**From:** FX-6 Personal Privacy
**To:** stephanie.jennings@emcbc.doe.gov; william.backous@emcbc.doe.gov; thomas.johnson@em.doe.gov; lance.martin@emcbc.doe.gov; debbie.kramer@emcbc.doe.gov; Gregg Dempsey/LV/USEPA/US@EPA; Craig Cooper/R9/USEPA/US@EPA; Nicole Moutoux/R9/USEPA/US@EPA; Mary Aycock/R9/USEPA/US@EPA; Dana Barton/R9/USEPA/US@EPA; David Cooper/R9/USEPA/US@EPA; Jared Blumenfeld/R9/USEPA/US@EPA
**Cc:** RBrausch@dtsc.ca.gov; MMalinow@dtsc.ca.gov; Gabrams@dtsc.ca.gov; LRainey@dtsc.ca.gov; SCallery@dtsc.ca.gov; mfellows@nasa.gov; Cowens@waterboards.ca.gov; Thomas.D.Gallacher@boeing.com; Philip.D.Rutherford@Boeing.com; Kamara.Sams@boeing.com; wendy@p2-solution.com; dhung@waterboards.ca.gov; dixie.a.hambrick@us.mwhglobal.com; TSecking@dtsc.ca.gov; DSheeks1@dtsc.ca.gov; ruckert@saic.com; WondolleckJT@cdm.com
**Subject:** Why the definition of the SRE is important today
**Date:** 08/02/2010 03:23 AM
**Attachments:** Radioactivity at SSFL 031109(rev 3).pdf
NIOSH to Congress ssfl2cong-156.pdf

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Dear Stephie,

First, I want to apologize for my behavior at the WHNC Environment Committee meeting last week.

I wanted to be there to see the DOE presentation. I had believed that you and Bill Backous were to be there. Then, about 5:30 PM that day, I saw a new agenda for the committee meeting. There was the addition of a video - one that I had seen several times before.

This video - the Warren Olny report, was from 1979. It made reference to many reactors besides the SRE including, I believe, the Borax 1 and the Hallum Reactor. I am "familiar" with these reactors and the SL-1 reactor as well. Borax 1 and the SL-1 are used as examples in our community. I believe that many people think that they were at Santa Susana. And I believe that some think someone was impaled in the SRE. <u>I have heard stories like this.</u> And of course, Borax and the SL - 1 were both in Idaho. Borax 1 was deliberately pushed to make it fail as an experiment.

http://web.archive.org/web/20021224231121/http://www.anlw.anl.gov/anlw_history/reactors/borax_i.html - Borax 1
http://en.wikipedia.org/wiki/SL-1 - SL- 1

Of course, the story behind Hallum is that they were supposed to have learned from the SRE how to "build a better reactor". There was a failure at Hallum - and I have been told - it was a million to clean it up or $6 million to clean it up and go back on line. The decision of the AEC at the time, was to go to another design. Of course, that is a story from someone that worked at Hallum - I don't have the documentation to back that story up.

I listened to that video presentation that night, and I took extensive notes. I wanted to make comments that they never called it "a meltdown" - I think they called it a serious accident. They said that they had many documents from a FOIA request. Channel 4 news got their footage from the DOE library (they stated).

I had printed out some Wikipedia articles regarding these reactors. And I had printed out the NIOSH conclusions that were sent to Congress (attached) and I read this conclusion:

**"NIOSH did not identify any evidence from the petitioners or from other resources that would establish that the class was exposed to radiation during a discrete incident likely to have involved exceptionally high-level exposures, such as a nuclear criticality incident, as defined under 42 C.F.R. § 83.13(c)(3)(i)."**

While I recognize that we will not know exactly what contamination still remains at Santa Susana, I am trying to understand the health risk to my community TODAY. I rely on the health studies that have been done to date - many of which are summarized on the ETEC website.

When you read Dr. Morgenstern's conclusions, he considers whether the increased level of thyroid cancer is from the perchlorate use at the SSFL, or from a "partial meltdown".

Many people say that they are ***"tired of Chris"*** saying "there was no meltdown". I have gotten into a lot of trouble with that statement. Why do I do it? Again, as always, I want to take away the fear that a "partial meltdown" release of radionuclides was significant enough to cause an elevated incidence of cancer in my community.

I do not have the technical skills to make that statement on my own. I keep looking to you, the DOE, and other agencies for support so that we can reduce the fear of that one incident in the community.

Now we have Cesium on NASA property that is being held up. I stand up and say - "it could be from fallout". "Whether it is or it isn't, the landfill determines the level of Cesium in the soil that is acceptable - it does not matter what our Background is." And I get in trouble for saying that.

And now, I am facing the Outfall 8 issue. I believe them when Boeing's contractors say that the Uranium and the Thorium could be from naturally occurring sources.

**I assume - and I trust -** that if they are not in compliance or they are at alarming levels, that Cassandra Owens will be asking for further tests.

All of this is complicated by Dr. Rucker's paper on what are the historic radionuclides at Santa Susana. And of course, the radionuclides that were used in the operations are some of the exact same ones as in Outfall 8 - Uranium 238, 235, 234, Thorium 232, and 228.

So just when I am ready to believe Boeing and say - and I have said: "There are no exceedences currently of radionuclides in AREA IV - and that is where you would expect to see them." And I say: "If these radionuclides are 'blowing offsite every time the wind blows', I would expect to see them in the storm water." "And I say: the primary exceedences are the dioxins and the heavy metals". I say: "there are no exceedences of TCE in the surface water". "They have sampled down stream for TCE in the LA River - this is not a primary contaminant of concern in the TMDLs for the City of LA - they are looking at Trash, Metals, Bacteria, and some other COCs that are site specific".

I try to give balance to the activist community who continue to believe that this site is so heavily contaminated that it is causing cancers in Oak Park, etc.

I ***need*** technical support for my statements. I am told there are not increased levels of radioactive cesium and iodine that have been found off site - or even on site that would indicate an event of the scale that most of the SSFL community believes still occurred at the SRE.

I appreciate very much the DOE's Expert Panel - which did resolve my fears. I appreciate the fact that the DOE and the EPA are doing the former worker interviews. And I appreciate all of the meetings that I am invited to by all of the agencies.

Now, we have the Boeing lawsuit continuing potentially another year - as a start. We do not have the DTSC Background Study. Every time I hear about another fire - my head just thinks of Doug Sheeks and what he is going through - the fear he has that we will lose our Background sites.

Some how, we need to get the information to the community before these radionuclide Background Studies are done. It is a shame that the EPA included some people in their discussions early on, and not all of us. If we had all been included at some level when those technical meetings went on - we did not have to all go into the field - there would not be such a diverse set of opinions as to what was up there and what the EPA intends to do as there is today.

Craig Cooper of the EPA stated on the "CAG" webex that the "EPA TASC" issue caused the problems / confusion in the community. The problems in the community are not due to TASC - they are due to a large part of the community feeling like they are not being heard, and another group feeling that they represent everyone.

I will conclude with my apologies to Stephie and to all - but I do not know how we are going to change the fractured nature of this community without better education. And if the community is not going to accept the opinions of the RPs, and the EPA cannot give an opinion of health risk before the characterization is done, then I ask - where is the California Department of Health Radiological Division? Why are they not on board?

Dr. Rucker's paper very specifically refers to Jerry Hensley's request for a list of potential radionuclides. So why don't we have Jerry still here, or someone else from the Dept of Health to answer our questions?

***So again, Stephie, I am sorry***. But when I came prepared to comment, and I was not allowed to comment on that video - "There is no debate" - I am sorry that "I blew".

We cannot say that the past is the past and move on to cleanup if the most recent health risk assessment for the community refers to a "partial meltdown" as the potential cause for thyroid cancer in my community. And I cannot believe that no effort is made to correct the WHNC regarding this website regarding a "meltdown." I just do not have - as you have seen - the technical skills or power to erase that term from my community's beliefs. Since not all had the benefit of seeing the SRE Expert Panel, and since I do not see many people taking the time as you suggested (Stephie) at the Workgroup last Spring to watch about 5 hours of videos and decide for yourself, I would like to request a letter from the DOE that summarizes the DOE's position on the term "meltdown", "partial meltdown", and the risk to my community from this one incident - please.

Please read below.

***Thank you Stephie.***

*Chris Rowe*

http://www.etec.energy.gov/Health-and-Safety/UOMStudy.html

## University of Michigan School of Public Health Study

In March 2007, Dr. Hal Morgenstern released a cancer incidence study of the communities surrounding SSFL:

- Cancer Incidence in the Community Surrounding the Rocketdyne Facility in Southern California, March 2007

This study had been commissioned by the Agency for Toxic Substances Disease Registry. The study concluded that:

- *Associations between distance from SSFL and cancer incidence differed by type of cancer outcome. Standardized incidence rate ratios were close to 1, indicating little or no association, for total cancers and radiosensitive cancers among adults; but the incidence rate of chemosensitive cancers was slightly elevated during both follow-up periods in the population living within 2 miles of SSFL. Results for the 9 specific cancers revealed some elevated incidence rates between 1988 and 1995 among persons living within 2 miles of SSFL. Specifically, the standardized incidence rate ratio was greater than 1.6 for cancers of blood and lymph tissue, bladder, thyroid, and upper aerodigestive tract. Between 1996 and 2002, the rate ratio among persons living within 2 miles of SSFL was greater than 1.6 for thyroid cancer. There were too few childhood cancers to yield informative results.*

- ***The strongest and most consistent association observed in this study was for thyroid cancer, which was associated with distance from SSFL in both follow-up periods. This finding may have public-health significance because perchlorate, a component of rocket fuel used in large quantities at SSFL, is known to disrupt thyroid function, it has been shown to induce thyroid tumors in laboratory animals, and there is evidence from two other investigations that***

***perchlorate migrated offside to contaminate the groundwater in areas surrounding SSFL. In addition, findings from one of those other studies suggest that the 1959 partial meltdown of a nuclear reactor at SSFL could have released appreciable amounts of radioactive cesium and iodine, which might have increased the incidence of thyroid cancer in the population surrounding SSFL.*** *Furthermore, our results for cancers of the bladder, blood and lymph tissue, and upper aerodigestive tract are consistent with associations observed in the UCLA Worker Study between mortality from these cancers and occupational exposures to radiation and chemicals.* ***It is important to recognize that associations observed between distance from SSFL and the incidence of specific cancers are based on small numbers of cases in the region closest to SSFL. Thus, these associations are estimated imprecisely and may represent chance findings. In addition, observed associations may have been biased by certain methodologic limitations—use of distance from SSFL as a crude proxy measure for environmental exposures, mobility of the residential population before and during the follow-up period, and lack of information on other cancer risk factors, such as cigarette smoking and socioeconomic status, that might distort the observed associations.***

- *Despite the methodologic limitations of this study, the findings suggest there may be elevated incidence rates of certain cancers near SSFL that have been linked in previous studies with hazardous substances used at Rocketdyne, some of which have been observed or projected to exist offsite. There is no direct evidence from this investigation, however, that these observed associations reflect the effects of environmental exposures originating at SSFL. Given these provocative findings and unanswered questions, it is tempting to recommend further analyses or future studies to address the health concerns of the community. Unfortunately, it is not clear at this time whether such additional analyses or studies will be sufficient to determine whether operations and activities at Rocketdyne affected, or will affect, the risk of cancer in the surrounding neighborhoods.*

THE SECRETARY OF HEALTH AND HUMAN SERVICES
WASHINGTON, D.C. 20201

April 5, 2010

The Honorable Joseph R. Biden, Jr.
President of the United States Senate
Washington, D.C. 20510

Dear Mr. President:

Pursuant to the Energy Employees Occupational Illness Compensation Program Act of 2000 and 42 C.F.R. pt. 83, a petition was filed on behalf of workers from Area IV of the Santa Susana Field Laboratory in Santa Susana, California, to be added to the Special Exposure Cohort (SEC).

The Centers for Disease Control and Prevention's (CDC) National Institute for Occupational Safety and Health (NIOSH) evaluated the petition and presented its findings to the Advisory Board on Radiation and Worker Health (Board) on February 9, 2010. The Board considered the petition, and on March 8, 2010, I received the Board's recommendation concerning this petition. I have also received the deliberations, findings, and recommendations of the Director of NIOSH and the Director of CDC. Based on this information, I have designated the following class for addition to the SEC:

> All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area of Area IV of the Santa Susana Field Laboratory from January 1, 1959 through December 31, 1964, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.

The criteria and findings upon which this designation is based are provided in the enclosed report.

Please contact me if you have any further questions regarding this matter.

Sincerely,

[Signature on file]

Kathleen Sebelius
Secretary

Enclosure

THE SECRETARY OF HEALTH AND HUMAN SERVICES
WASHINGTON, D.C. 20201

April 5, 2010

The Honorable Harry Reid
Majority Leader
United States Senate
Washington, D.C. 20510

Dear Senator Reid:

Pursuant to the Energy Employees Occupational Illness Compensation Program Act of 2000 and 42 C.F.R. pt. 83, a petition was filed on behalf of workers from Area IV of the Santa Susana Field Laboratory in Santa Susana, California, to be added to the Special Exposure Cohort (SEC).

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[Signature on file]

Kathleen Sebelius
Secretary

Enclosure

THE SECRETARY OF HEALTH AND HUMAN SERVICES
WASHINGTON, D.C. 20201

April 5, 2010

The Honorable Mitch McConnell
Minority Leader
United States Senate
Washington, D.C. 20510

Dear Senator McConnell:

Pursuant to the Energy Employees Occupational Illness Compensation Program Act of 2000 and 42 C.F.R. pt. 83, a petition was filed on behalf of workers from Area IV of the Santa Susana Field Laboratory in Santa Susana, California, to be added to the Special Exposure Cohort (SEC).

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[Signature on file]

Kathleen Sebelius
Secretary

Enclosure

THE SECRETARY OF HEALTH AND HUMAN SERVICES
WASHINGTON, D.C. 20201

April 5, 2010

The Honorable Nancy Pelosi
Speaker of the House of Representatives
Washington, D.C. 20515

Dear Madam Speaker:

Pursuant to the Energy Employees Occupational Illness Compensation Program Act of 2000 and 42 C.F.R. pt. 83, a petition was filed on behalf of workers from Area IV of the Santa Susana Field Laboratory in Santa Susana, California, to be added to the Special Exposure Cohort (SEC).

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Please contact me if you have any further questions regarding this matter.

Sincerely,

[Signature on file]

Kathleen Sebelius
Secretary

Enclosure

THE SECRETARY OF HEALTH AND HUMAN SERVICES
WASHINGTON, D.C. 20201

April 5, 2010

The Honorable John A. Boehner
Minority Leader
House of Representatives
Washington, D.C. 20515

Dear Congressman Boehner:

Pursuant to the Energy Employees Occupational Illness Compensation Program Act of 2000 and 42 C.F.R. pt. 83, a petition was filed on behalf of workers from Area IV of the Santa Susana Field Laboratory in Santa Susana, California, to be added to the Special Exposure Cohort (SEC).

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The criteria and findings upon which this designation is based are provided in the enclosed report.

Please contact me if you have any further questions regarding this matter.

Sincerely,

[Signature on file]

Kathleen Sebelius
Secretary

Enclosure

HHS Designation of Additional Members of the
Special Exposure Cohort
under the
Energy Employees Occupational Illness Compensation Program Act of 2000

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Designating a Class of Employees from

Santa Susana Field Laboratory
Santa Susana, California

## I. Designation

I, Kathleen Sebelius, Secretary of Health and Human Services, designate the class of employees defined in Section II of this report for addition to the Special Exposure Cohort (SEC), as authorized under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), 42 U.S.C. § 7384q.

| | |
|---|---|
| __April 5, 2010________ | _[Signature on file]_________ |
| Date | Kathleen Sebelius |

## II. Employee Class Definition

All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area of Area IV of the Santa Susana Field Laboratory from January 1, 1959 through December 31, 1964, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.

## III. Designation Criteria and Recommendations

Pursuant to 42 U.S.C. § 7384q, for the class defined in Section II of this report, the Secretary has determined, and the Advisory Board on Radiation and Worker Health (Board) has recommended, that

(1) it is not feasible to estimate with sufficient accuracy the radiation dose that the class received; and

(2) there is a reasonable likelihood that such radiation dose may have endangered the health of members of the class.

The SEC final rule states in 42 C.F.R. § 83.13(c)(1) that it is feasible in two situations to estimate the radiation dose that the class received with sufficient accuracy. First, the rule states that radiation doses may be estimated with sufficient accuracy if NIOSH has established that it has access to sufficient information to estimate the maximum radiation dose for every type of cancer for which radiation doses are reconstructed that could have been incurred under plausible circumstances by any member of the class. Alternatively, radiation doses may be estimated with sufficient accuracy if NIOSH has established that it has access to sufficient information to estimate the radiation doses of members of the class more precisely than a maximum dose estimate.

The Board, pursuant to 42 U.S.C. § 7384q, advised the Secretary to designate the class as an addition to the SEC in a letter received by the Secretary on March 8, 2010.

## IV. Designation Findings

Feasibility of Estimating Radiation Doses with Sufficient Accuracy

The Secretary established the feasibility determination for the class of employees covered by this report based upon the findings summarized below.

- NIOSH lacks sufficient information, which includes biological monitoring data, sufficient air monitoring information, or sufficient process and radiological source information, to allow it to estimate with sufficient accuracy the potential internal exposures to various radionuclides to which the proposed class may have been subjected during the time period from January 1, 1959 through December 31, 1964.

- NIOSH finds that it is likely feasible to reconstruct external dose, including occupational medical dose, for Area IV of the Santa Susana Field Laboratory (SSFL-Area IV) workers with sufficient accuracy.

- There is currently one SEC class of SSFL-Area IV workers associated with a previous NIOSH evaluation of SEC petition SEC-00093. The period currently designated for inclusion in the SEC extends from January 1, 1955 through December 31, 1958.

- Through the course of ongoing dose reconstruction, continued data capture efforts, and investigations associated with SEC-00093, NIOSH has since determined that although bioassay data are available for some monitored workers after 1958, some SSFL-Area IV workers could have received intakes of radioactive materials after 1958 that went unmonitored.

- Pursuant to 42 C.F.R. § 83.13(c)(1), NIOSH determined that there is insufficient information to either: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred under plausible circumstances by any member of the class; or (2) estimate the radiation doses of members of the class more precisely than a maximum dose estimate.

- The Board concurred with the NIOSH evaluation and recommended the proposed class for addition to the SEC.

- During the development of co-worker distribution models to assess potential internal dose to unmonitored workers, NIOSH has found that the available bioassay data have limitations which preclude the development of adequate co-worker models for the years prior to 1965. Therefore, NIOSH determined that it is necessary to propose an extension of the SEC time period for the SSFL-Area IV site through December 31, 1964.

- Although NIOSH found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at SSFL-Area IV during the period from January 1, 1959 through December 31, 1964, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

Health Endangerment

The Secretary established the health endangerment determination for the class of employees covered by this report based upon the findings summarized below.

(1) Pursuant to 42 C.F.R. § 83.13(c)(3), NIOSH established that there is a reasonable likelihood that such radiation doses may have endangered the health of members of the class. Pursuant to 42 C.F.R. § 83.13(c)(3)(ii), NIOSH specified a minimum duration of employment to satisfy this health endangerment criterion as "having been employed for a number of work days aggregating at least 250 work days within the parameters established for this class or in combination with work days within the parameters (excluding aggregate work day requirements) established for one or more other classes of employees in the Cohort."

(2) NIOSH did not identify any evidence from the petitioners or from other resources that would establish that the class was exposed to radiation during a discrete incident likely to have involved exceptionally high-level exposures, such as a nuclear criticality incident, as defined under 42 C.F.R. § 83.13(c)(3)(i).

(3) The Board concurred with NIOSH's finding that the health of the class may have been endangered and defined the class according to the 250-work day requirement specified under 42 C.F.R. § 83.13(c)(3)(ii).

## V. Effect and Effective Date of Designation

The Secretary submits this report on the designation of one additional class to the SEC for review by Congress, pursuant to 42 U.S.C. §§ 7384*l*(14)(C)(ii) and 7384q(c)(2)(A), as amended by the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Pub. L. No. 108-375 (codified as amended in scattered sections of 42 U.S.C.). Pursuant to 42 U.S.C. § 7384*l*(14)(C)(ii), as amended by the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Pub. L. No. 108-375 (codified as amended in scattered sections of 42 U.S.C.), the designation in this report will become effective 30 days after the date of this report's submission to Congress "unless Congress otherwise provides."

## VI. Administrative Review of Designation

The health endangerment determination of the designation provided in this report may be subject to an administrative review within HHS, pursuant to 42 C.F.R. § 83.18(a). On the basis of such a review, if the Secretary decides to expand the class of employees covered by this designation, the Secretary would transmit a supplementary report to Congress providing the expanded employee class definition and the criteria and findings on which the decision was based.

# Radionuclides Related to Historical Operations at the Santa Susana Field Laboratory Area IV

**Thomas L. Rucker, Ph.D.**
**Science Applications International Corporation**

**March 2009**

08-136(NE)/031109

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# ACRONYMS

| | |
|---|---|
| AETR | Advanced Epithermal Thorium Reactor |
| BWR | boiling water reactor |
| CDPH | California Department of Public Health |
| DOE | U.S. Department of Energy |
| ETEC | Energy Technology Engineering Center |
| IAEA | International Atomic Energy Agency |
| KEWB | Kinetics Experiment Water Boiler |
| kW | kilowatts |
| NMDF | Nuclear Materials Development Facility |
| PRG | Preliminary Remediation Goal |
| PWR | pressurized water reactor |
| SRE | Sodium Reactor Experiment |
| SSFL | Santa Susana Field Laboratory |
| USEPA | U.S. Environmental Protection Agency |

# GLOSSARY

activation product – A nuclide, usually radioactive, formed by the bombardment and adsorption in material with neutrons, protons, or other nuclear particles.

AEC – U.S. Atomic Energy Commission

corrosion product – An activation product formed by the activation and oxidation of metals

criticality – The condition in which a system is capable of sustaining a nuclear chain reaction.

DOE – U.S. Department of Energy

EIS – Environmental Impact Statement –

Environmental Assessment – A written environmental analysis which is prepared pursuant to the National Environmental Policy Act to determine whether a federal action would significantly affect the environment and thus require the preparation of a more detailed environmental impact statement.

EPA – U. S. Environmental Protection Agency

ETEC – Energy Technology Engineering Center

fertile material – Substance capable of becoming fissile, by capturing neutrons, possibly followed by radioactive decay; e.g., Th-232, U-238, Pu-240.

fission product – A nuclide resulting either from the fission of heavy elements such as uranium. Usually radioactive.

fission yield – The fraction of fissions resulting in a specified fission product.

fuel assembly – Structured collection of fuel rods or elements, the unit of fuel in a reactor.

fuel cladding – The outer metal jacket of a nuclear fuel element or target. It prevents fuel corrosion and retains fission products during reactor operation and subsequent storage, as well as providing structural support. Zirconium alloys, stainless steel, and aluminum are common cladding materials.

fuel element – Arrangement of a number of fuel rods into which the nuclear fuel is inserted in the reactor.

half-life – The time in which one-half of the atoms of a particular radioactive isotope disintegrate to another nuclear form. Half-lives vary from millionths of a second to billions of years.

high enriched uranium – Uranium enriched to at least 20% U-235.

kW – Kilowatt – A unit of electrical power equal to a thousand watts (joules per second)

low enriched uranium – Uranium enriched to less than 20% U-235. (That in power reactors is usually 3.5 - 5.0% U-235.)

MW – Megawatt – A unit of electrical power equal to a million watts (joules per second).

noble gas – Any of the chemically inert gaseous elements of the helium group in the periodic table

nuclear activation (neutron) cross section – Cross section: a measure of the probability of an interaction between a particle and a target nucleus, expressed in barns (1 barn = $10^{-24}$ $cm^2$).

nuclear reactor – A device in which a fission chain reaction can be initiated, maintained, and controlled. It's essential components are fissionable fuel, moderator, shielding, control rods, and coolant.

nuclide – Elemental matter made up of atoms with identical nuclei, therefore with the same atomic number and the same mass number (equal to the sum of the number of protons and neutrons). Also referred to as an isotope of an element.

Particle Accelerator – A scientific instrument that increases the kinetic energy of charged particles

PRG – Preliminary remediation goal

radioactive decay – The change of one radioactive nuclide into a different nuclide by the spontaneous emission of alpha, beta, or gamma rays, or by electron capture. The end product is a less energetic, more stable nucleus. Each decay process has a definite half-life.

radionuclide – An unstable nuclide that undergoes spontaneous transformation, emitting radiation.

Risk – The probability of a detrimental effect of exposure to a hazard.

risk assessment – The science of studying the amount of risk associated with doing something.

site characterization – A general term applied to the investigation activities at a specific location that examine natural phenomena and human-induced conditions

spent fuel – Used fuel assemblies removed from a reactor after several years use and treated as waste.

spontaneously fissionable (fissile) material – Substance in which fission occurs spontaneously, not induced by an incident particle.

SSFL - Santa Susana Field Laboratory

transuranic –Refers to any element whose atomic number is higher than that of uranium (atomic number 92), including neptunium, plutonium, americium, and curium. All transuranic elements are produced artificially and are radioactive.

unirradiated – Not having been exposed to radiation

Van de Graaff Generator – Electrical device that produces a high voltage by building up a charge of static electricity

# EXECUTIVE SUMMARY

This paper summarizes the history of nuclear operations at Area IV of the Santa Susana Field Laboratory (SSFL) and identifies the radionuclides that would result from documented processes. It also presents the results of calculations estimating which radionuclides could still be present in 2009 in significant concentrations. These calculations are based on the initial production amounts of each radionuclide and the radioactive decay that has occurred since last production. The calculations also evaluate the proportion each radionuclide would contribute to the overall potential dose and associated risk in SSFL Area IV.

The U.S. Department of Energy (DOE) commissioned this research because the California Department of Public Health (CDPH), other regulators, and stakeholders asked, in various ways based on a 2008 analysis of existing data, the question: Based on existing knowledge of SSFL Area IV nuclear operations and documented radioactive decay rates, what radionuclides might still be present in significant quantities today? In response, this paper was prepared using the best available references describing the history of radiological operations, processes, and uses. As the research progressed, DOE recognized that this paper could be used as a reference point not only to respond to the various questions CDPH and others had asked, but also to meet two additional objectives: 1) to ensure that all significant contributors to risk are included in the planned Risk Assessment, and 2) to help prioritize analytical requirements for new samples to be collected for pending studies.

This paper does not evaluate the actual concentrations remaining in the environment in Area IV of the SSFL or the actual dose. The actual concentrations present in Area IV of SSFL and resulting risk to the public depend on the quantities of radionuclides that were released to the environment and the residual persistence in the environs after previous remediation efforts. These questions will be the focus of the radiological survey and sampling efforts currently in planning by the U.S. Environmental Protection Agency (USEPA). Rather, this paper documents the potential that each identified radionuclide could be present in significant quantities today, and in what proportion, relative to the other radionuclides identified based on the initial production rates and the rate at which each radionuclide decays. In other words, this paper provides a list of “suspects” – radionuclides that both were in the area and are known to have relatively long half-lives. DOE offers this list so the teams of scientists investigating contamination can prioritize their sampling and analyses toward these radionuclides. Following completion of the EPA’s radiological survey and a chemical survey being conducted by the California Department of Toxic Substances Control, DOE will prepare human health and ecological risk assessments to support of the Environmental Impact Statement currently being developed.

The majority of process related radionuclides at the SSFL Area IV resulted from the following activities:

- operation of ten nuclear reactors,
- operation of seven criticality test facilities,
- manufacture of reactor fuel assemblies,
- disassembly and inspection of reactors and used reactor fuel assemblies,
- preparation of radioactive materia1 for disposal, and
- on-site storage of nuclear materia1.

In addition to those operations, smaller quantities of radionuclides were associated with small-scale laboratory work that included the following activities:

- fabrication, use, and storage of radioactive sources;

- research focused on reprocessing spent nuclear fuel;
- operation of particle accelerators;
- research using radioisotopes; and
- miscellaneous operations and commercial items that used radioactive materials.

In compiling the list of radionuclides that would have been produced as a result of the documented reactor processes, radionuclides with half-lives of less than one year were not considered. The rationale for this is that only 0.0000002 percent or less of the original radioactivity would remain after the 29 years (the time that has elapsed since the last reactor was shut down on the SSFL Area IV, in 1979 and the production of radionuclides ceased). Standard references were used to calculate the relative quantities of fission products, activation products, and transuranic radionuclides in spent reactor fuel that were produced in reactors. These quantities were then adjusted to account for radioactive decay since cessation of reactor operations. The identity and amounts of accelerator and research related radionuclides were also qualitatively evaluated.

This evaluation has resulted in a list of radionuclides that are expected to have the potential to contribute more than 1 percent of the current activity. They are:

**Reactor fuel-related radionuclides:**

- Two isotopes of thorium – Th-228, Th-232;
- Three isotopes of uranium – U-234, U-235, U-238;
- Four isotopes of plutonium – Pu-238, Pu-239, Pu-240, Pu-241;

**Reactor fission products:**

- tritium (H-3, an isotope of hydrogen,),
- strontium-90 (Sr-90),
- cesium-137 (Cs-137),
- promethium-147 (Pm-147), and
- europium-155 (Eu-155);

**Reactor activation products:**

- beryllium-10 (Be-10),
- cadmium-113m (Cd-113m),
- barium-133
- two isotopes of europium – Eu-152 and Eu-154, and
- uranium-233 (U-233);

**Reactor-produced transuranics:**

- Four isotopes of plutonium – Pu-238, Pu-239, Pu-240, Pu-241;
- Americium-241 – Am-241; and
- Curium-244 – Cm-244;

**Accelerator activation product:**

- tritium (H-3); and

**Research-related radionuclides**:

- Three isotopes of uranium – U-234, U-235, U-238;
- Neptunium-237 (Np-237);
- Four isotopes of plutonium – Pu-238, Pu-239, Pu-240, Pu-241;
- Cobalt-60 (Co-60);
- Cesium-137 (Cs-137); and
- Promethium-147 (Pm-147).

This paper also presents the results of calculations to evaluate the risk these radionuclides could present. The radionuclides that contribute greater than 1 percent of the risk potential are the same as those listed above, except that reactor produced fission products Pm-147 and Eu-155, reactor produced activation product Co-60, and all reactor produced transuranics are not included in the list that produce 99% of the risk. However, some of these are still included as fuel or research related risk contributors. A combined priority list based on the potential to contribute to greater than 1% of the risk include: Th-228, Th-232, U-234, U-235, U-238, Pu-238, Pu-239, Pu-240, Pu-241, H-3, Sr-90, Ba-133, Cs-137; Be-10, Cd-113m, Eu-152, Eu-154, U-233, Np-237, Co-60, Cs-137, and Pm-147.

The calculation of relative activity, dose and risk percentage could be quantitatively performed only for radionuclides in spent reactor fuel, based on the available references for relative production amounts. However, radionuclides associated with fuel elements, used in the manufacture of fuel assemblies, are assumed to have the potential to contribute more than 1 percent of the current activity, dose, and risk. Based on this review, radionuclides in spent nuclear fuel and fuel elements are expected to be responsible for the majority of SSFL Area IV contamination. Information about specific concentrations, quantities, and processes for radionuclides from research was not available. Thus, no relative activity information is available and therefore the relative potential for contamination is unknown. As a conservative precaution, these radionuclides were included in the list above, for further investigation.

# 1.0 BACKGROUND AND PURPOSE

The U.S. Department of Energy (DOE) commissioned this paper to summarize the history of nuclear operations at Area IV of the Santa Susana Field Laboratory (SSFL) and identify the radionuclides that would result from those operations. DOE asked that the author also present the results of calculations to estimate which radionuclides could still be present in 2009 in significant concentrations. This paper provides these calculations based on the initial production amounts of each radionuclide relative to all others and the radioactive decay that would have occurred since production. The calculations also evaluate how much each radionuclide would contribute to the overall potential dose and associated risk that might exist at SSFL Area IV.

DOE initiated this paper after receiving comments on the *Draft Gap Analysis Report*, submitted for regulatory and public review on June 1, 2008. That analysis was conducted to determine whether existing data for Area IV of the SSFL are adequate for the purpose of developing and evaluating risk-based cleanup alternatives in an Environmental Impact Statement. Section 3.2.5.3 and Table 3-11 of the report included a list of radionuclide contaminants of interest developed from the radionuclide lists contained in the *Historical Site Assessment*[1] and the *Environmental Assessment*[2], supplemented by additional radionuclides based on process knowledge from other reactor and fuel separation facilities, and filtered on the basis of half-life considerations.

In his review comments, Jerry Hensley of the California Department of Public Health–requested that a new listing of all radionuclides generated during reactor operations be provided and pared down using industry acceptable methods (i.e., radiological half-life). A number of other reviewers from both regulatory agencies and the public also requested more information about radionuclides related to all processes and their current significance, while taking into consideration half-life and health affects. This information is needed not only to make sure that all significant contributors to risk are included in the Risk Assessment, but also to aid in prioritization of target analytes for new sampling and analysis efforts. This paper has been drafted to respond to these comments and requests and to meet these needs.

# 2.0 SCOPE AND APPROACH

This paper provides a review and an evaluation of the best available references describing the historical radiological operations related to nuclear reactor research conducted by DOE and its predecessor, the Atomic Energy Commission. This review also includes other nuclear research operations conducted in Area IV of the SSFL. While it is understood that the process descriptions in these references may not be exhaustive, it is believed that they represent the types of radiological processes that were performed in Area IV of the SSFL and include all significant radionuclides that were used or produced. DOE plans to compile further records and information related to all activities at the Energy Technology Engineering Center (ETEC). As part of that effort, former workers and all stakeholders will be asked to provide any

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[1] *Historical Site Assessment of Area IV Santa Susana Field Laboratory,* Sapere Consulting, Inc. and The Boeing Company for the Department of Energy Under Contract DE-AC03-99SF21530 (May 2005). http://etec.energy.gov/Cleanup/Historical-Site-Assessment html

[2] *Environmental Assessment for Cleanup and Closure of the Energy Technology and Engineering Center*, *Final.* U.S. Department of Energy, NNSA Service Center, Oakland, CA (March 2003). http://etec.energy.gov/Regulation/RegDocs/ETECEA.pdf

information that they may have on the history of the site. If additional information is collected that changes the conclusions of this paper, it will be revised accordingly.

This paper provides a summary of the historical nuclear operations and a list of the associated process-related radionuclides produced at Area IV of the SSFL. It also includes an evaluation of the probability for each radionuclide to be present at the current time in significant concentrations. The potential for these radionuclides to be present today has been evaluated based on the initial relative production amounts and radioactive decay since their production. The significance of each radionuclide's contribution to the potential dose and associated risk is also evaluated.

This paper does not evaluate the actual concentrations remaining in the environment in Area IV of the SSFL or the actual dose, but only the potential for the current likely presence of each radionuclide relative to all others. The actual concentrations present in Area IV of SSFL and resulting risk to the public depend on the quantities of radionuclides that were released to the environment and the residual persistence in the environs after previous remediation efforts. That subject will be the focus of the radiological survey and sampling efforts currently in planning by the U.S. Environmental Protection Agency (USEPA) and the dose/risk assessment aspect of the EIS that DOE will complete following the USEPA's radiological survey and a chemical survey being conducted by the California Department of Toxic Substances Control.

## 3.0 SUMMARY OF NUCLEAR OPERATIONS AT SSFL AREA IV

Process-related radionuclides at the SSFL Area IV were primarily the result of the following activities:

- Operation of ten nuclear reactors
- Operation of seven criticality test facilities
- Manufacture of reactor fuel assemblies
- Disassembly and inspection of reactors and used reactor fuel assemblies
- Preparation of radioactive material for disposal
- On-site storage of nuclear materia1.

Small-scale laboratory work, including the activities below, may have involved smaller amounts of radionuclides:

- Fabrication, use, and storage of radioactive sources
- Research on reprocessing used reactor fuel
- Operation of particle accelerators
- Research using radioisotopes
- Miscellaneous operations
- Commercial items which use radioactive materials.

# 4.0 SSFL AREA IV NUCLEAR OPERATIONAL HISTORY

## 4.1 REACTOR OPERATIONAL HISTORY[3]

The majority of man-made radioactivity at the SSFL Area IV is the result of the operation of ten nuclear reactors. The amount of radioactivity generated by a nuclear reactor depends largely on the amount of heat it generates, called its "power level" and the period of operation. The reactors operated at the SSFL Area IV all had very low power levels: six had power levels of less than 100 kilowatts (kW), three had power levels of 600 to 1,000 kW, and one (the Sodium Reactor Experiment, or SRE) was a 20-MW test reactor. By comparison, reactors used for commercial electric power generation have thermal power levels of 3,000 MW or more. The reactors were operated in seven different facilities. Table 1 lists the name, facility number, facility name, nominal power level, and operating period for each reactor.

**Table 1. Reactor Operations at the SSFL Area IV**

| Operation Name | Bld. No. | Facility Name | Power Level (kW) | Operating Period |
|---|---|---|---|---|
| KEWB | 4073 | Kinetics Experiment Water Boiler | 1 | 7/56 - 11/66 |
| L-85/AE-6 | 4093 | L-85 Nuclear Experiment Reactor | 3 | 11/56 - 2/80 |
| SRE | 4143 | Sodium Reactor Experiment | 20,000 | 4/57 - 2/64 |
| SER | 4010 | S8ER Test Facility | 50 | 9/59 - 12/60 |
| S2DR | 4024 | SNAP Environmental Test Facility | 65 | 4/61 - 12/62 |
| STR | 4028 | Shield Test Irradiation Facility | 50 | 12/61 - 7/64 |
| S8ER | 4010 | S8ER Test Facility | 600 | 5/63 - 4/65 |
| STIR | 4028 | Shield Test Irradiation Facility | 1,000 | 8/64 - 6/73 |
| Sl0FS3 | 4024 | SNAP Environmental Test Facility | 37 | 1/65 - 3/66 |
| S8DR | 4059 | SNAP Ground Prototype Test Facility | 619 | 5/68 - 12/69 |

A nuclear reactor contains nuclear fuel, usually in the form of fuel assemblies, composed of spontaneously fissionable (fissile) radioactive material (e.g., uranium-235 or plutonium-239) plus other materials that may be added for various purposes (e.g., thorium as a fertile material for breeding fissile uranium-233), contained within a cladding material (usually steel, aluminum, or zirconium). The fuel assemblies are arranged in a "core", and surrounded by reflectors, shields, and containment vessels. Two reactors that operated at the SSFL Area IV, the Kinetics Experiment Water Boiler (KEWB) and the L-85 Nuclear Experimentation Reactor, had fuel in the form of liquid solutions of uranyl sulfate.

Several incidents occurred during the operating history of the SRE reactor that resulted or may have resulted in the releases of radionuclides to the environment.[4] On June 4, 1959, an explosion resulting from an unexpected hydrogen-oxygen reaction blew a fuel element (which was undergoing sodium cleaning) out of the wash cell. On July 12, 1959, depletion in coolant flow due to blockage resulted in overheating and damage to 13 of 43 fuel elements in the reactor core. During this event, the damage to these assemblies caused failure of cladding on all seven fuel rod elements, and some iron uranium

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[3] Largely abstracted from *Nuclear Operations at Rockwell's Santa Susana Field Laboratory – A Factual Perspective,* Rockwell International, Report N001E1R000017, October 2, 1990, Revision B. http://www.etec.energy.gov/library/Reading-Room/N001ER000017_Nuclear_Operations_SSFL_Factual_Perspective.pdf.

*4 Historical Site Assessment of Area IV Santa Susana Field Laboratory,* Sapere Consulting, Inc. and The Boeing Company, for the U.S. Department of Energy, Ventura County, CA, Contract DE-AC03-99SF21530, May 2005.

eutectic was molten for a short period of time in the reactor. Between 5,000 and 10,000 curies of mixed fission product were released and contained in the primary sodium cooling system. It was calculated that approximately 28 curies of Kr-85 were released to the environment. The Kr-85, a non-reactive noble gas, quickly dispersed in the atmosphere. On March 12, 1960, a contaminated sodium fire broke out in the sodium service vault. Personnel were unable to extinguish the fire with standard suppression equipment, so the vault was sealed and purged with argon gas. Accidents such as these and others likely resulted in accidental release of radionuclides to the environment likely contributed to the overall amount of contamination that may be present. However, they in general do not impact the identity or relative ratios of radionuclides to each other that may currently be present in the environment, which is the subject of this paper.

### 4.2 CRITICALITY TEST FACILITY OPERATIONAL HISTORY[5]

A controlled nuclear chain reaction can be sustained only when neutrons generated by fission of reactor fuel balance the neutrons used up and lost. When the reactor is adjusted so that this balance is achieved, it is said to be "critical". Criticality can be achieved in several ways: for example, by bringing parts of a core of fissionable material together (to reduce the number of neutrons that escape); by removing control rods (to reduce the number of neutrons captured in the control rods); or by increasing the number of neutrons reflected back into the core. Criticality Test Facilities were built to conduct tests to aid in developing new types of reactors by determining exactly which reactor configurations are critical, and how criticality is affected by changes in reactor design parameters. The criticality tests were operated at a very low power level (up to a few hundred watts), and neutron levels were correspondingly very low. Thus, a large number of criticality tests could be performed in the same test facility without generating much by-product radioactivity.

There were dozens of criticality tests performed at the SSFL Area IV, in seven different test facilities. Table 2 lists these facilities, their facility number, and operating periods.

**Table 2. Criticality Test Facilities at the SSFL Area IV**

| Facility Name | Bldg. No. | Operating Period | Notes |
|---|---|---|---|
| SNAP Critical Test | 4373 | 1957-63 | First SNAP-2 Criticality Tests |
| Organic Moderated Reactor | 4009 | 1958-67 | Basic Tests of Reactor Concept |
| Sodium Graphite Reactor | 4009 | 1958-67 | Basic Tests of Reactor Concept |
| SNAP Critical Equipment Lab. | 4012 | 1961-71 | Later SNAP Criticality Tests |
| Fast Critical Experiment Lab. | 4100 | 1961-74 | Started as AETR |
| SNAP Flight System | 4019 | 1962 | SNAP Flight System Criticality |
| SNAP Transient Test | 4024 | 1967-69 | SNAP Transient Response Tests |

### 4.3 MANUFACTURE OF REACTOR FUEL ASSEMBLY OPERATIONAL HISTORY[6]

As part of the nuclear reactor development work performed for the government, three different reactor fuel manufacturing operations were performed at the SSFL Area IV. The first operation was the assembly of fuel elements for the SRE. The second operation was manufacture of plutonium fuel, and the third was

[5] *Nuclear Operations at Rockwell's Santa Susana Field Laboratory - A Factual Perspective.*
[6] *Ibid.*

manufacture of uranium carbide fuel. There was also a Fuel Storage Facility, which stored the special nuclear materials (enriched uranium and plutonium) used to make reactor fuel.

The SRE fuel elements were assembled in the Engineering Test Building (Building 4003). Uranium and thorium metal slugs were brought into the SSFL Area IV for this purpose. In Building 4003, the slugs were loaded into metal tubes, the interstices were filled with sodium metal, and the tubes sealed. Although fuel elements for three cores for the SRE were prepared, only two cores were used. The third core was eventually shipped off-site. The first core did not contain thorium.

The plutonium fuel manufacturing facility, named the Nuclear Materials Development Facility (NMDF; Building 4055) was built specifically for development work involving plutonium. It was completed in 1967 and operated until 1979. Its operating history is summarized in Table 3.

**Table 3. Operations at the Nuclear Materials Development Facility**

| Operating Period | Operation |
|---|---|
| 1967 – 1968 | Development of Analysis Technologies for uranium-plutonium oxide fuels |
| 4/68 – 6/69 | Recycle of scrap uranium-plutonium fuel |
| 7/68 – 6/70 | Development of technologies to mix tungsten into uranium-plutonium carbide fuel |
| 4/70 – 9/70 | Preparation of samples for uranium-plutonium oxide irradiation studies |
| 9/70 – 3/74 | Idle |
| 1974 – 1975 | Bench scale tests-recovery of plutonium from simulated waste |
| 1975 – 5/77 | Mixed uranium-plutonium carbide fuel fabrication |
| 5/77 – 11/78 | Partial decontamination and clean-up |
| 11/78 – 11/79 | Fabrication of depleted uranium carbide fuel |
| 11/79 – 10/82 | Idle |
| 10/82 – 10/86 | Decontamination and decommissioning |
| 7/87 | Released for unrestricted use |

The uranium carbide fuel manufacturing pilot plant was located in Building 4005. It was a small scale production facility built to study the operations associated with manufacturing reactor fuel assemblies from uranium carbide. In the pilot plant, uranium oxide was reacted with graphite to convert it to uranium carbide, which was then cast into pellets, machined to the proper dimensions, and assembled into cladding tubes to make fuel assemblies. Initial operations were performed using depleted uranium to test the equipment, and then enriched uranium was used to make fuel assemblies for a critical assembly to be built at another AEC facility. Operations were completed in about nine months in 1967 and production was small.

The plutonium and uranium carbide materials were stored in the Fuel Storage Facility (Building 4064), a vault built to provide secure storage for fissile fuel material (enriched uranium and plutonium) used to make reactor fuel. The building was constructed above ground using concrete and concrete blocks, to comply with the AEC criteria for vaults for storage of fissionable materials.

## 4.4 DISASSEMBLY AND EXAMINATION OF REACTORS AND USED REACTOR FUEL ASSEMBLIES OPERATIONAL HISTORY[7]

A number of operations were performed remotely in the heavily-shielded Hot Laboratory (Building 4020, the "Hot Lab"), built in Area IV specifically to provide protection during processes that involved highly radioactive materials. These operations included:

- **Fuel assembly performance evaluation.** During reactor test operations, it was often necessary to examine reactor fuel assemblies and other test specimens to evaluate their performance, which involved the handling and examination of highly radioactive items.

- **Reactor disassembly.** When each reactor operation was completed and the reactor was no longer needed, it was removed from its operating location, disassembled, its fuel removed, its radioactive structure cut into pieces suitable for shipment. The radioactive material was shipped off-site for appropriate processing and disposal. Given the highly radioactive materials involved, the disassembly, fuel removal, and size reduction operations were also usually performed using the Hot Lab.

- **Used fuel disassembly.** The Hot Lab was also the location for work involving disassembly of used irradiated reactor fuel generated outside the SSFL. The fuel elements were shipped into the Hot Lab, disassembled or separated from their cladding material, and the separated materials then packaged and shipped back to other DOE facilities.

- **Manufacture of sealed sources.** The Hot Lab was also used to manufacture sealed radioactive sources (see below), for performing leak testing of sources, and for cutting and machining operations involving radioactive cobalt-60.

Construction of the Hot Lab facility was completed in 1959, and it was in use until 1989 when it underwent decontamination and decommissioning. The Hot Lab was used to examine fuel and/or components from the SRE, SER, S2DR, S8ER, S8DR, and S10FS3 reactors operated at the SSFL Area IV, the OMR and SGR criticality test facilities at SSFL, and the Piqua, Ohio, reactor. It was also used to declad fuel from the, EBR-I, EBR-11, Hallam, Fermi, and SEFOR reactors from other DOE sites.

## 4.5 FABRICATION, USE, AND STORAGE OF RADIOACTIVE SOURCES OPERATIONAL HISTORY[8]

A variety of radiation sources were used in the Hot Lab, including sources essential for the calibration of the many instruments required to detect and measure radioactivity at SSFL Area IV. These instruments were calibrated periodically, using known quantities and types of radioactivity. The calibration "sources" produced in the Hot Lab consisted of sealed containers that contained small measured quantities of radioisotopes. Other sources produced in the Hot Lab included those for radiography, irradiation testing, and other applications. The sources manufactured in the Hot Lab were used in various facilities at the SSFL Area IV and elsewhere. Only a small number of commercially-produced calibration sources are currently in use at SSFL today. Although approximately 140,000 curies of radioactive material (primarily promethium-147) were fabricated into sources at the Hot Lab, only a small fraction of this activity would remain today due to radioactive decay of the sources produced, especially for the promethium sources.

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[7] *Ibid.*
[8] *Ibid.*

## 4.6 RESEARCH ON REPROCESSING USED REACTOR FUEL OPERATIONAL HISTORY9

The used fuel assemblies from nuclear reactors contain unused fuel materials, and fission and activation products. Rockwell International developed a process to effect a partial separation of used fuel, removing part of the fission products so that the material could be used again as reactor fuel. Tests were performed in a well-shielded “Hot Cave” located in Building 4003, the Engineering Test Building. These experiments used up to one-kilogram quantities of un-irradiated uranium and thorium, and up to 100-gram quantities of highly irradiated materials.

## 4.7 PARTICLE ACCELERATORS OPERATIONAL HISTORY[10]

Another way to generate artificial (induced) radioactivity is to bombard a target material with atomic particles that have been accelerated to high speeds by means of a particle accelerator. A common form of particle accelerator is a "Van de Graaff generator", which uses a high-voltage electrostatic field to accelerate atomic particles to high speeds (high energy levels). Collisions of these particles with a target material (such as aluminum or tritium) can generate small amounts of radioactivity. Rockwell International operated a Van de Graaff generator in Building 4030, which bombarded tritium targets with deuterons to produce neutrons. The neutrons produced could then make other materials radioactive. A second Van de Graaff generator was operated at the SRE facility, generating neutrons for neutron activation analyses of materials. It was removed before the SRE facility was decontaminated and decommissioned.

## 4.8 RESEARCH USING RADIOISOTOPES OPERATIONAL HISTORY[11]

Some of the research done at the SSFL Area IV required the use of special radioisotopes. For these tests, small quantities of specially-prepared radioisotopes were brought to the SSFL Area IV, used in laboratories under controlled conditions, and then either transported off the facility or stored under controlled conditions if reuse was required.

One research program that required the use of radioisotopes was the TRUMP-S program. Although the original plan was to perform the TRUMP-S tests in the Hot Lab at the SSFL Area IV, the test program was transferred to the University of Missouri. Seventy-five grams of depleted uranium, five grams of plutonium, and four grams of neptunium, were received at SSFL Area IV and stored in Building 4064 before being shipped to the University of Missouri sometime after 1990.

Another research program that used a radioisotope was a corrosion test program carried out in the Corrosion Testing Laboratory (Building 4023). A pumped sodium corrosion test loop was built there, and used to study the deposition behavior of activation products (Mn-54 and Co-60) in flowing sodium so as to develop more effective traps for these isotopes. An activated piece of fuel cladding containing these isotopes was used in these tests.

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[9] *Ibid.*
[10] *Ibid.*
[11] *Ibid.*

# 5.0 RADIONUCLIDES ASSOCIATED WITH IDENTIFIED OPERATIONS AT SSFL AREA IV

## 5.1 RADIONUCLIDES ASSOCIATED WITH REACTOR OPERATIONS, CRITICALITY TEST OPERATIONS, MANUFACTURE OF NEW AND DISASSEMBLY OF USED FUEL ASSEMBLIES, AND WASTE OPERATIONS

Operation of a nuclear reactor not only involves the use of nuclear fuel but also creates three types of by-product radionuclides: fission products, transuranics, and activation products. When part of the fissionable material in the fuel element is used up, or when a reactor is decommissioned, the fuel elements are removed from the reactor. These "spent" fuel elements contain the fission products and transuranics generated by operation of the reactor, and the activation products in the cladding. The same radionuclides associated with reactor operations are also associated with criticality test operations, disassembly of used fuel assemblies, and waste operations since they all are related to nuclear reactor operations either as new fuel or fuel with the operational by-products.

### 5.1.1 Reactor Fuel Radionuclides

The radioactive material placed in a reactor includes the nuclear fuel made up of fissile radioactive material (e.g., uranium, plutonium) and other fuel elements (thorium). Although plutonium fuel was manufactured at SSFL Area IV, according to operational descriptions, none of the reactors or criticality experiments operated at SSFL Area IV used plutonium as a fuel. Many of the reactors, including the SRE, which produced the vast majority of the power generated, used a low-enriched uranium fuel (3-5 percent U-235 content by mass). However, according to operational descriptions, all reactors and criticality experiments associated with the SNAP program used high-enriched uranium fuel (~90 percent U-235 content by mass).[12]

The majority of the radioactivity in unirradiated low-enriched uranium fuel is from the isotope U-234 (75-85 percent) with lesser amounts from U-238 (10-20 percent) and only a few percent from U-235 (~5 percent).[13] In high-enriched unirradiated uranium fuel, even more of the radioactivity is from U-234 (~95 percent) while very little is from U-238 (less than 1 percent).[14] Sometimes thorium was added as a fertile material for breeding fissile U-233. According to operational descriptions, only two reactors, the Sodium Reactor Experiment (SRE) and the Advanced Epithermal Thorium Reactor (AETR), used fuel that contained thorium as a fertile material.[15] The thorium isotopes present in the fuel would have consisted mainly of Th-232 and its decay progeny Th-228 in partial equilibrium.

The manufactured plutonium fuel was actually a mixture of plutonium and uranium oxide pellets. The plutonium would have been comprised primarily of the isotope Pu-239, with lesser amounts of Pu-238, Pu-240, and Pu-241. There is no evidence that the plutonium fuel or plutonium-uranium mixed fuel was ever used as fuel for any onsite reactors.[16]

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[12] *Ibid.*
[13] *Health Physics Manual of Good Practices for Uranium Facilities*, Idaho National Engineering Laboratory, EGG-2530 UC-41, June 1988, pp 2-10 and *Guide of Good Practices for Occupational Radiological Protection In Uranium Facilities*, U.S Department of Energy, DOE-STD-1136-2000, August 2000, pp 2-10.
[14] *Ibid.*
[15] *Nuclear Operations at Rockwell's Santa Susana Field Laboratory - A Factual Perspective.*
[16] *Ibid.*

Table 4 provides a summary of fuel element radionuclides that were used or produced in SSFL Area IV and thus could be potentially present today.

**Table 4. Summary of Fuel Element Radionuclides**

| Radionuclide | Half-life |
|---|---|
| Th-228 | 1.91 y |
| Th-232 | 14.0 by |
| U-234 | 246 ky |
| U-235 | 704 my |
| U-238 | 4.47 by |
| Pu-238 | 87.7 y |
| Pu-239 | 24.1 ky |
| Pu-240 | 6.56 ky |
| Pu-241 | 14.4 y |

y = years; k = thousand; m = million; b = billion

### 5.1.2 Fission Product Radionuclides

When a reactor is operated, atoms of the fissionable material split, releasing neutrons and heat, and leaving behind fragments of the atom called fission products, which are made up of various isotopes of newly-formed elements. Some of the neutrons that are released are captured by other atoms of fissionable material, and these capture reactions cause some of these atoms to split, releasing more neutrons and heat and creating more fission products in a controlled "chain reaction."

Most of the fission products from a nuclear reactor are radioactive, emitting beta and gamma radiation. The fission products and fission yields can be identified by review of a Chart of the Nuclides.[17] Fission yields vary by radionuclide in a predictable way as demonstrated by Figure 1. The fission yields vary depending on the fuel used and are identified separately in the chart for U-235 fission products and U-233 fission products. All of the fissile fuel utilized at SSFL Area IV was U-235; however, since thorium was utilized as a fertile fuel element in some reactor experiments, some fission products from U-233 fission may have also been produced. Tables 5 and 6 list the fission product radionuclides with half-lives longer than one year along with their fission yields for U-235 and U-233 fuel, respectively.

A one-year cut-off was used since the decay of radionuclides is exponentially proportional to their half-life. After 10 half-lives, the fraction of original radioactivity remaining is reduced by decay to 0.1 percent. After 20 half-lives it is reduced to 0.0001 percent of the original amount and after 30 half-lives, it is reduced to 0.0000001 percent of the original amount. After 10 half-lives of any radionuclide, the radioactivity is usually considered to be insignificant. However, to be conservative, any radionuclide with a half-life greater than one year was included in the potential list. Any radionuclide with a half-life of less than one year will only have 0.0000002 percent or less of the original activity remaining after 29 years that have elapsed since the last reactor was shut down on the SSFL Area IV and the production of fission products ceased.

[17] *Nuclides and Isotopes,* Fourteenth Edition, General Electric Company, 1989.

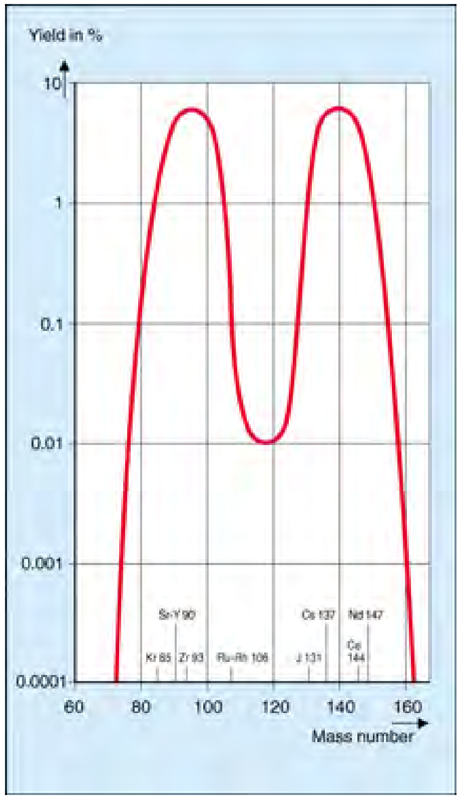


**Figure 1. Fission yields vary by radionuclide in a predictable way**

**Table 5. U-235 Fission Products with Half-Lives Greater Than Oue Year**

| Radionuclide | $t_{1/2}$ (years) | Fission Yield[a] (%) | Relative Activity Yield | Activity Yield (%) | Relative Activity at 29 Years | Activity % at 29 Years |
|---|---|---|---|---|---|---|
| Se-79 | 6.50E+04 | 0.044 | 4.69E-07 | 0.0000 | 3.77E-05 | 0.0003 |
| Kr-85 | 10.73 | 1.317 | 8.51E-02 | 6.8337 | 0.00E+00 | 0.0000 |
| Sr-90 | 29.1 | 5.8 | 1.38E-01 | 11.0970 | 6.88E+00 | 47.9597 |
| Zr-93 | 1.50E+06 | 6.37 | 2.94E-06 | 0.0002 | 2.36E-04 | 0.0016 |
| Tc-99 | 2.13E+05 | 6.1 | 1.99E-05 | 0.0016 | 1.59E-03 | 0.0111 |
| Ru-106 | 1.02E+00 | 0.401 | 2.73E-01 | 21.8884 | 2.56E-05 | 0.0002 |
| Pd-107 | 6.50E+06 | 0.145 | 1.55E-08 | 0.0000 | 1.24E-06 | 0.0000 |
| Cd-113 | 9.00E+15 | 0.015 | 1.16E-18 | 0.0000 | 9.28E-17 | 0.0000 |
| Sb-125 | 2.76E+00 | 0.031 | 7.79E-03 | 0.6258 | 4.01E-03 | 0.0280 |
| Sn-126 | 1.00E+05 | 0.059 | 4.09E-07 | 0.0000 | 3.28E-05 | 0.0002 |
| I-129 | 1.57E+07 | 0.75 | 3.31E-08 | 0.0000 | 2.66E-06 | 0.0000 |
| Cs-134 | 2.07E+00 | 7.66E-06 | 2.57E-06 | 0.0002 | 2.43E-07 | 0.0000 |
| Cs-135 | 2.30E+06 | 6.54 | 1.97E-06 | 0.0002 | 1.58E-04 | 0.0011 |
| Cs-137 | 3.02E+01 | 6.19 | 1.42E-01 | 11.4231 | 7.20E+00 | 50.2146 |
| Sm-146 | 1.03E+08 | 3 | 2.02E-08 | 0.0000 | 1.62E-06 | 0.0000 |
| Pm-147 | 2.62E+00 | 2.25 | 5.94E-01 | 47.7515 | 2.36E-01 | 1.6461 |
| Eu-152 | 1.35E+01 | 1.79E-10 | 9.20E-12 | 0.0000 | 2.63E-10 | 0.0000 |
| Eu-154 | 8.59E+00 | 1.91E-07 | 1.54E-08 | 0.0000 | 2.45E-07 | 0.0000 |
| Eu-155 | 4.71E+00 | 0.032 | 4.71E-03 | 0.3783 | 1.96E-02 | 0.1371 |
| | | Highlighted | | 99 | | 100 |

[a]All fission yields taken from *Nuclides and Isotopes*, Fourteenth Edition, General Electric Company, 1989, except for Cs-134, Eu-152, and Eu-154 which came from ***Fission Product Yields,*** WIMS Library Update Project, NAPC Nuclear Data Section, IAEA, since these isotopes are shielded from other fission products in the same mass fission decay chain.

$t_{1/2}$ = half-life

**Table 6. U-233 Fission Products with Half-Lives Greater Than Oue Year**

| Radionuclide | $t_{1/2}$ (years) | Fission Yield[a] (%) | Relative Activity Yield | Activity Yield (%) | Relative Activity at 29 Years | Activity % at 29 Years |
|---|---|---|---|---|---|---|
| Se-79 | 6.50E+04 | 0.14 | 1.49E-06 | 0.0001 | 1.32E-04 | 0.0007 |
| Kr-85 | 10.73 | 2.25 | 1.45E-01 | 12.8995 | 0.00E+00 | 0.0000 |
| Sr-90 | 29.1 | 6.8 | 1.62E-01 | 14.3750 | 8.91E+00 | 49.7785 |
| Zr-93 | 1.50E+06 | 6.37 | 2.94E-06 | 0.0003 | 2.61E-04 | 0.0015 |
| Tc-99 | 2.13E+05 | 4.9 | 1.59E-05 | 0.0014 | 1.42E-03 | 0.0079 |
| Ru-106 | 1.02E+00 | 0.25 | 1.70E-01 | 15.0775 | 1.77E-05 | 0.0001 |
| Pd-107 | 6.50E+06 | 0.114 | 1.22E-08 | 0.0000 | 1.08E-06 | 0.0000 |
| Cd-113 | 9.00E+15 | 0.019 | 1.46E-18 | 0.0000 | 1.30E-16 | 0.0000 |
| Sb-125 | 2.76E+00 | 0.12 | 3.02E-02 | 2.6766 | 1.71E-02 | 0.0958 |
| Sn-126 | 1.00E+05 | 0.22 | 1.52E-06 | 0.0001 | 1.35E-04 | 0.0008 |
| I-129 | 1.57E+07 | 1.6 | 7.06E-08 | 0.0000 | 6.27E-06 | 0.0000 |
| Cs-134 | 2.07E+00 | 2.69E-04 | 9.02E-05 | 0.0080 | 9.41E-06 | 0.0001 |
| Cs-135 | 2.30E+06 | 6.3 | 1.90E-06 | 0.0002 | 1.69E-04 | 0.0009 |
| Cs-137 | 3.02E+01 | 6.81 | 1.56E-01 | 13.8855 | 8.75E+00 | 48.9070 |
| Sm-146 | 1.03E+08 | 2.56 | 1.72E-08 | 0.0000 | 1.53E-06 | 0.0000 |
| Pm-147 | 2.62E+00 | 1.74 | 4.60E-01 | 40.8014 | 2.02E-01 | 1.1270 |
| Eu-152 | 1.35E+01 | 7.70E-09 | 3.96E-10 | 0.0000 | 1.25E-08 | 0.0000 |
| Eu-154 | 8.59E+00 | 2.10E-06 | 1.69E-07 | 0.0000 | 2.97E-06 | 0.0000 |
| Eu-155 | 4.71E+00 | 0.021 | 3.09E-03 | 0.2743 | 1.42E-02 | 0.0796 |
| | | Highlighted | | 100 | | 100 |

[a]All fission yields taken from *Nuclides and Isotopes*, Fourteenth Edition, General Electric Company, 1989, except for Cs-134, Eu-152, and Eu-154 which came from *Fission Product Yields,* WIMS Library Update Project, NAPC Nuclear Data Section, IAEA, since these isotopes are shielded from other fission products in the same mass fission decay chain.
$t_{1/2}$ = half-life

The fission yield is the fraction of fissions resulting in the specified isotope and is shown in the table in percentages. Since the radioactive decay of an isotope is proportional to $\ln(2)/t_{½}$ (where $t_{½}$ is the radionuclide half-life), the relative activity of each of the fission products produced in a reactor is the product of the fission yield and that factor. This product is shown in Tables 5 and 6 as the "Relative Activity Yield" which is the relative amount of each fission product isotope produced. The percentage of total fission product activity is also shown in Tables 5 and 6. These figures were decay-corrected for the 29 years that have elapsed since the last reactor was shut down on the SSFL Area IV, resulting in the activity percentage at 29 years shown in the tables. It should be noted that it is assumed that all Kr-85 has dissipated into the atmosphere and is no longer onsite since it is a noble (non-reactive) gas. It can be seen from Tables 5 and 6 that greater than 98 percent of the remaining fission product activity is composed of Sr-90 and Cs-137, with most of the remaining percentage being from Pm-147 for both uranium fuels.

Till and Meyer[18] quantified the potentially significant fission products found in spent reactor fuels. Table 7 contains this list of fission products also decay-corrected for the 29 years that have elapsed since the last reactor was shut down on the SSFL Area IV. It can be observed from the Table 7 that greater than 98-percent of the remaining fission product activity is composed of the same radionuclides as identified above, Sr-90, Cs-137, and Pm-147, with most of the rest being from Eu-155.

[18] J. E. Till and H. R. Meyer, *Radiological Assessment, A Textbook on Environmental Dose Analysis,* U.S. Nuclear Regulatory Commission, NUREG/CR-3332, 1983, pp.1-49.

**Table 7. Representative Quantities of Potentially Significant Fission Products in Spent Reactor Fuels**

| Radionuclide | $t_{1/2}$ (years) | Activity Ci/tonne[a] | Activity (%) | Relative Activity at 29 Years | Activity % at 29 Years |
|---|---|---|---|---|---|
| H-3 | 12.3 | 800 | 0.0592 | 1.91E-02 | 0.2397 |
| Kr-85 | 10.73 | 1.05E+04 | 0.7776 | 0.00E+00 | 0.0000 |
| Sr-90 | 29.1 | 6.00E+04 | 4.4434 | 2.75E+00 | 34.5752 |
| Zr-93 | 1.50E+06 | 2.00E+00 | 0.0001 | 1.48E-04 | 0.0019 |
| Tc-99 | 2.13E+05 | 1.50E+01 | 0.0011 | 1.11E-03 | 0.0139 |
| Ru-106 | 1.02E+00 | 8.20E+05 | 60.7264 | 7.12E-05 | 0.0009 |
| Sb-125 | 2.76E+00 | 1.30E+04 | 0.9627 | 6.17E-03 | 0.0774 |
| I-129 | 1.57E+07 | 4.00E-02 | 0.0000 | 2.96E-06 | 0.0000 |
| Cs-134 | 2.07E+00 | 1.00E+05 | 7.4057 | 8.71E-03 | 0.1094 |
| Cs-135 | 2.30E+06 | 1.20E+00 | 0.0001 | 8.89E-05 | 0.0011 |
| Cs-137 | 3.02E+01 | 1.06E+05 | 7.8500 | 4.95E+00 | 62.1287 |
| Pm-147 | 2.62E+00 | 2.00E+05 | 14.8113 | 7.32E-02 | 0.9193 |
| Eu-155 | 4.71E+00 | 4.00E+04 | 2.9623 | 1.54E-01 | 1.9325 |
| | Highlighted | | 99 | | 100 |

[a]Ci/tonne = curies per metric ton; $t_{1/2}$ = half-life

To identify and quantify the major dose contributors from the identified fission products, the calculated activity percentage at 29 years has been multiplied by the USEPA inhalation,[19] ingestion,[20] and external[21] dose conversion factors. The resulting percentages of the total effective dose equivalents are shown in Table 8. It can be seen from Table 8 that Sr-90 and Cs-137 comprise greater than 99 percent of the dose potential from fission products. Likewise, to identify and quantify the major risk contributors from the identified fission products, the calculated activity percentage at 29 years has been divided by the USEPA Preliminary Remediation Goals (PRGs) for both Residential and Agricultural land use scenarios. The resulting percentages of the relative risk are shown in Table 9. It can be seen from Table 9 that Sr-90 and Cs-137 comprise greater than 99 percent of the risk from fission products.

### 5.1.3 Activation Product Radionuclides

Some of the neutrons that are released by fuel fissions are captured by the fuel cladding or the other materials in the reactor, and others escape from the reactor and are captured in the shielding around the reactor; far fewer escape the shielding and are captured in the reactor building or the ground. When a neutron is captured by an atom other than the fuel, such as in the fuel cladding or the reactor structure or shield, it creates a new isotope called an "activation product". The term activation product is reserved for products of neutron capture by materials other than the fuel, such as structural components of the nuclear reactor, the reactor coolant, control rods or other neutron poisons, or materials in the environment of the reactor. Most of these activation products are also radioactive, emitting beta and gamma radiation.

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[19] Federal Guidance Report No.11, *Limiting Values of Radionuclide Intake And Air Concentration and Dose Conversion Factors For Inhalation, Submersion, And Ingestion*; Environmental Protection Agency, EPA-520/1-88-020, September 1988.
[20] *Ibid.*
[21] Federal Guidance Report No.12, *External Exposure To Radionuclides In Air, Water, And Soil; Environmental* Protection Agency, EPA-520/1-88-020, September 1988.

**Table 8. Potential Dose from Representative Quantities of Potentially Significant Fission Products in Spent Reactor Fuels**

| Radionuclide | Activity % at 29 Years | Inhalation DCF | Relative Inhalation Dose at 29 Years | Inhalation Dose % at 29 Years | Ingestion DCF | Relative Ingestion Dose at 29 Years | Ingestion Dose % at 29 Years | External DCF[a] | Relative External Dose at 29 Years | External Dose % at 29 Years |
|---|---|---|---|---|---|---|---|---|---|---|
| H-3 | 0.2397 | 1.73E-11 | 4.15E-12 | 0.0000 | 1.73E-11 | 4.15E-12 | 0.0002 | 0 | 0.00E+00 | 0.0000 |
| Kr-85 | 0.0000 | 0 | 0.00E+00 | 0.0000 | 0 | 0.00E+00 | 0.0000 | 4.58E-20 | 0.00E+00 | 0.0000 |
| Sr-90 | 34.5752 | 3.51E-07 | 1.21E-05 | 95.5177 | 3.85E-08 | 1.33E-06 | 61.2531 | 2.95E-21 | 1.02E-19 | 0.0149 |
| Zr-93 | 0.0019 | 8.67E-08 | 1.61E-10 | 0.0013 | 4.48E-10 | 8.33E-13 | 0.0000 | 0.00E+00 | 0.00E+00 | 0.0000 |
| Tc-99 | 0.0139 | 2.25E-09 | 3.14E-11 | 0.0002 | 3.95E-10 | 5.51E-12 | 0.0003 | 5.74E-22 | 8.01E-24 | 0.0000 |
| Ru-106 | 0.0009 | 1.29E-07 | 1.15E-10 | 0.0009 | 7.40E-09 | 6.61E-12 | 0.0003 | 3.93E-18 | 3.51E-21 | 0.0005 |
| Sb-125 | 0.0774 | 3.30E-09 | 2.56E-10 | 0.0020 | 7.59E-10 | 5.88E-11 | 0.0027 | 7.66E-18 | 5.93E-19 | 0.0869 |
| I-129 | 0.0000 | 4.69E-08 | 1.74E-12 | 0.0000 | 7.46E-08 | 2.78E-12 | 0.0001 | 6.92E-20 | 2.57E-24 | 0.0000 |
| Cs-134 | 0.1094 | 1.25E-08 | 1.37E-09 | 0.0108 | 1.98E-08 | 2.17E-09 | 0.0996 | 2.83E-17 | 3.09E-18 | 0.4534 |
| Cs-135 | 0.0011 | 1.23E-09 | 1.37E-12 | 0.0000 | 1.91E-09 | 2.13E-12 | 0.0001 | 1.85E-22 | 2.06E-25 | 0.0000 |
| Cs-137 | 62.1287 | 8.63E-09 | 5.36E-07 | 4.2200 | 1.35E-08 | 8.39E-07 | 38.5948 | 1.09E-17 | 6.77E-16 | 99.2194 |
| Pm-147 | 0.9193 | 1.06E-08 | 9.74E-09 | 0.0767 | 2.83E-10 | 2.60E-10 | 0.0120 | 2.29E-22 | 2.11E-22 | 0.0000 |
| Eu-155 | 1.9325 | 1.12E-08 | 2.16E-08 | 0.1703 | 4.13E-10 | 7.98E-10 | 0.0367 | 7.94E-19 | 1.53E-18 | 0.2248 |
| Highlighted | 100 | | | 100 | | | 100 | | | 100 |

[a]Based on 5 cm contamination depth.
DCF = Dose Conversion Factor

**Table 9. Potential Risk from Representative Quantities of Potentially Significant Fission Products in Spent Reactor Fuels**

| Nuclide | Activity % at 29 Years | Residential PRG | Relative Residential Risk at 29 Years | Residential Risk % at 29 Years | Agricultural PRG | Relative Agricultural Risk at 29 Years | Agricultural Risk % at 29 Years |
|---|---|---|---|---|---|---|---|
| H-3 | 0.2397 | 2.28E+00 | 1.05E-01 | 0.0088 | 1.60E-01 | 1.50E+00 | 0.0020 |
| Kr-85 | 0.0000 | 2.41E+01 | 0.00E+00 | 0.0000 | 2.23E+01 | 0.00E+00 | 0.0000 |
| Sr-90 | 34.5752 | 2.31E-01 | 1.50E+02 | 12.5578 | 1.39E-03 | 2.49E+04 | 32.4436 |
| Zr-93 | 0.0019 | 3.38E+02 | 5.50E-06 | 0.0000 | 2.00E+02 | 9.30E-06 | 0.0000 |
| Tc-99 | 0.0139 | 2.50E-01 | 5.58E-02 | 0.0047 | 5.57E-03 | 2.50E+00 | 0.0033 |
| Ru-106 | 0.0009 | 2.25E+00 | 3.97E-04 | 0.0000 | 1.72E-01 | 5.20E-03 | 0.0000 |
| Sb-125 | 0.0774 | 4.62E-01 | 1.68E-01 | 0.0141 | 4.60E-01 | 1.68E-01 | 0.0002 |
| I-129 | 0.0000 | 5.96E-01 | 6.24E-05 | 0.0000 | 2.76E-05 | 1.35E+00 | 0.0018 |
| Cs-134 | 0.1094 | 1.57E-01 | 6.97E-01 | 0.0584 | 7.47E-03 | 1.46E+01 | 0.0191 |
| Cs-135 | 0.0011 | 1.78E+01 | 6.27E-05 | 0.0000 | 5.09E-03 | 2.19E-01 | 0.0003 |
| Cs-137 | 62.1287 | 5.97E-02 | 1.04E+03 | 87.3134 | 1.20E-03 | 5.18E+04 | 67.5291 |
| Pm-147 | 0.9193 | 1.03E+03 | 8.93E-04 | 0.0001 | 6.69E+02 | 1.37E-03 | 0.0000 |
| Eu-155 | 1.9325 | 3.80E+00 | 5.09E-01 | 0.0427 | 3.74E+00 | 5.17E-01 | 0.0007 |
| Highlighted | 100 | | | 100 | | | 100 |

The probability of an activation product being produced in a reactor is the product of a number of factors, including the concentration of the element being activated in the environment of the reactor, the abundance of the isotope in the element being activated, and the ability of a given material to capture neutrons (i.e., neutron cross section) for the isotope being activated. The International Atomic Energy Agency (IAEA) *Handbook on Nuclear Activation Cross Sections*[22] provides a list of elements and their isotopes with their abundance and their thermal neutron cross sections. A list of some example long-lived activation product radionuclides and the materials they may be produced from are shown in Table 10.[23] Since not only beryllium and cadmium but also europium are common neutron absorbers used in reactor control rods, Eu-152, and Eu-154 were added to the list and will be considered to be potentially present for purposes of developing a process related radionuclide list. In addition, since Th-232 was used as a fertile material in some reactor fuel, U-233 as an activation product will also be considered as potentially present for purposes of developing a process related radionuclide list. However, activation products will not be present unless the parent material was present in the environment of the reactor. Therefore, some of these activation products are not likely present at SSFL Area IV given that the parent material was not likely present in significant concentration in the environment of the reactor. These low probability activation products include Cl-36, Ar-39, Mo-93, Nb-93m, Nb-94, Tc-99 (except as a fission product), Ag-108m, Sn-121m, Pb-205, andPo-210. Table 11 presents a list of activation products that are typically present in nuclear power reactor coolants along with their relative concentrations for both boiling water reactor (BWR) and pressurized water reactor (PWR) coolants.[24] Although many of the reactors at SSFL Area IV were sodium-cooled reactors, this list provides an indication of additional activation products that may have been produced onsite. Many of the activation products listed in both Tables 9 and 10 have short half-lives relative to the 29 years time elapsed since any reactor was operational at SSFL Area IV and could have possibly produced them. Table 12 provides a summary list of long lived ($t_{½}$ > 1 year) activation products potentially present at SSFL Area IV.

Till and Meyer[25] quantified the corrosion products (a major subset of activation products) present in spent reactor fuels. Table 13 contains this list of corrosion products also decay corrected for the 29 years that have elapsed since the last reactor was shut down on the SSFL Area IV. It can be seen from the Table 13 that greater than 99 percent of the remaining corrosion product activity remaining is composed of Fe-55 and Co-60.

### 5.1.4 Transuranic Radionuclides

Some of the neutrons that are released by fuel fissions are captured by fuel element atoms that do not split, but instead form new isotopes, called “transuranics.” Although these radionuclides are created by “activation” in the reactor, they are generally considered to be a separate category than activation products. Transuranics are elements heavier than uranium, all of which are essentially man-made and do not naturally occur in significant quantities in nature. All of the transuranic radionuclides are radioactive, emitting alpha, beta, and/or gamma radiation.

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[22] *Handbook on Nuclear Activation Cross Sections,* Technical Reports Series No.156, International Atomic Energy Agency, Vienna, 1974.
[23] This table is licensed under the GNU Free Documentation License. It uses material from the Wikipedia article “Activation Products".
[24] Chien C. Lin, *Radiochemistry in Nuclear Power Reactors,* Nuclear Science Series, NAS-NS-3119, National Research Council, National Academy Press, Washington, D.C. 1996.
[25] J. E. Till and H. R. Meyer, pp.1-50.

**Table 10. Example Activation Products**

| Radionuclide | Half-life | Activation Parent |
|---|---|---|
| Tritium | 12.3 y | Lithium-6,7<br>Boron-10 |
| Beryllium-10 | 1.53 my | Boron-10 |
| Carbon-14 | 5,730 y | Nitrogen-14<br>Carbon-13 |
| Sodium-24 | 15.0 h | Sodium-23 |
| Chlorine-36 | 301 ky | Chlorine-35 |
| Argon-39 | 269 y | Argon-38 |
| Iron-55 | 2.73 y | Iron-54 |
| Nickel-59 | 76 ky | Nickel-58 |
| Cobalt-60 | 5.27 y | Cobalt-59 |
| Nickel-63 | 100 y | Nickel-62 |
| Molybdenum-93 | 3.5 ky | Molybdenum-92 |
| Niobium-93m | 16.1 y | Niobium-93 |
| Niobium-94 | 20.3 ky | Niobium-93 |
| Technetium-99 | 211 ky | Molybdenum-98 |
| Silver-108m | 108 y | Silver-107 |
| Cadmium-113m | 12.2 y | Cadmium-112 |
| Tin-121m | 56 y | Tin-120 |
| Ba-133 | 10.5 y | Ba-132 |
| Europium-152 | 13.5 y | Europium-151 |
| Europium-154 | 8.59 y | Europium-153 |
| Lead-205 | 15.3 my | Lead-204 |
| Polonium-210 | 138 d | Bismuth-209 |
| Uranium-233 | 159 ky | Thorium-232 |

h= hours; d = days; y = years; k = thousand; m = million; b = billion

**Table 11. Selected ANS Standard Radionuclide Concentrations in Reactor Coolants Activation Products (mCi/kg)**

| Radionuclide | Half-Life | BWR[a] | PWR[b] |
|---|---|---|---|
| H-3 | 12.3 y | 10 | 1,000 |
| N-16 | 7.1s | 60,000 | 60,000 |
| F-18 | 1.8h | 1.0 | — |
| Na-24 | 15h | 10 | 47 |
| P-32 | 14d | 0.2 | — |
| Cr-51 | 27d | 6.0 | 3.1 |
| Mn-54 | 312d | 0.07 | 1.6 |
| Mn-56 | 2.6h | 50 | — |
| Fe-55 | 2.7y | 1.0 | 1.2 |
| Fe-59 | 45d | 0.03 | 0.3 |
| Co-58 | 71d | 0.2 | 4.6 |
| Co-60 | 5.3y | 0.4 | 0.53 |
| Ni-63 | 100y | 0.001 | — |
| Cu-64 | 12.7h | 30 | — |
| Zn-65 | 244d | 0.2 | 0.51 |
| Ag-110m | 250d | 0.001 | 1.3 |
| W-187 | 24h | 0.3 | 2.5 |

[a] A reference BWR is a 3,400 MW BWR/5.
[b] A reference PWR is a 3,400 MW PWR with U-tube steam generators.
mCi/kg = millicuries per kilogram
s = seconds; h = hours; d = days; y = years
k = thousand; m = million; b = billion

**Table 12. Summary of Potential Long-Lived Activation Products**

| Radionuclide | Half-life |
|---|---|
| Tritium | 12.3 y |
| Beryllium-10 | 1.53 my |
| Carbon-14 | 5,730 y |
| Iron-55 | 2.73 y |
| Nickel-59 | 76 ky |
| Cobalt-60 | 5.27 y |
| Nickel-63 | 100 y |
| Cadmium-113m | 13 y |
| Ba-133 | 10.5 y |
| Europium-152 | 13.5 y |
| Europium-154 | 8.59 y |
| Uranium-233 | 159 ky |

y = years; k = thousand; m = million; b = billion

**Table 13. Representative Quantities of Corrosion Products in Spent Reactor Fuels**

| Radionuclide | $t_{1/2}$ (years) | Activity Ci/tonne[a] | Activity (%) | Relative Activity at 29 Years | Activity % at 29 Years |
|---|---|---|---|---|---|
| Mn-54 | 0.86 | 30,000 | 36.3636 | 3.36E-06 | 0.0011 |
| Fe-55 | 2.7 | 20,000 | 24.2424 | 1.39E-01 | 44.8079 |
| Fe-59 | 0.12 | 500 | 0.6061 | 2.33E-51 | 0.0000 |
| Co-58 | 0.2 | 30,000 | 36.3636 | 2.05E-29 | 0.0000 |
| Co-60 | 5.26 | 2000 | 2.4242 | 1.72E-01 | 55.1911 |
| | Highlighted | | 99 | | 100 |

[a]Ci/tonne = curies per metric ton; $t_{1/2}$ = half-life

To identify and quantify the major dose and related potential risk contributors from the identified corrosion products, the calculated activity percentage at 29 years has been multiplied by the USEPA inhalation,[26] ingestion,[27] and external[28] dose conversion factors. The resulting dose percentages are shown in Table 14.

It can be seen from Table 14 that Fe-55 and Co-60 comprise greater than 99 percent of the dose potential from corrosion products. Likewise, to identify and quantify the major risk contributors from the identified corrosion products, the calculated activity percentage at 29 years has been divided by the USEPA PRGs for both Residential and Agricultural land use scenarios. The resulting percentages of the relative risk are shown in Table 15. It can be seen from Table 15 that Co-60 contributes greater than 99 percent of the risk from corrosion products. The other potentially significant activation products not reflected in Tables 14 and 15 would include H-3, Be-10, C-14, Cd-113m, Ba-133, Eu-152, Eu-154, and U-233.

Till and Meyer[29] quantified the transuranics present in spent reactor fuels. Table 16 contains this list of transuranics also decay corrected for the 29 years that have elapsed since the last reactor was shut down on the SSFL Area IV. It can be seen from the Table 16 that greater than 99 percent of the remaining transuranics activity remaining is composed of Pu-238, Pu-239, Pu-240, Pu-241, Am-241, and Cm-244.

To identify and quantify the major dose and related potential risk contributors from the identified transuranics, the calculated activity percentage at 29 years has been multiplied by the USEPA inhalation,[30] ingestion,[31] and external[32] dose conversion factors. The resulting dose percentages are shown in Table 17. It can be seen from Table 17 that all of the listed transuranics except Pu-242 and Cm-242 combine to contribute greater than 99 percent of the dose potential from transuranics for at least one of the exposure pathways.

[26] Federal Guidance Report No.11.
[27] *Ibid.*
[28] Federal Guidance Report No.12.
[29] J. E. Till and H. R. Meyer, pp.1-50.
[30] Federal Guidance Report No.11.
[31] *Ibid.*
[32] Federal Guidance Report No.12.

**Table 14. Potential Dose from Representative Quantities of Corrosion Products in Spent Reactor Fuels**

| Radionuclide | Activity % at 29 Years | Inhalation DCF | Relative Inhalation Dose at 29 Years | Inhalation Dose % at 29 Years | Ingestion DCF | Relative Ingestion Dose at 29 Years | Ingestion Dose % at 29 Years | External DCF[a] | Relative External Dose at 29 Years | External Dose % at 29 Years |
|---|---|---|---|---|---|---|---|---|---|---|
| Mn-54 | 0.0011 | 1.81E-09 | 1.95E-12 | 0.0001 | 7.48E-10 | 8.08E-13 | 0.0002 | 1.51E-17 | 1.63E-20 | 0.0007 |
| Fe-55 | 44.8079 | 7.26E-10 | 3.25E-08 | 0.9875 | 1.64E-10 | 7.35E-09 | 1.7961 | 0 | 0.00E+00 | 0.0000 |
| Fe-59 | 0.0000 | 4.00E-09 | 3.00E-57 | 0.0000 | 1.81E-09 | 1.36E-57 | 0.0000 | 2.12E-17 | 1.59E-65 | 0.0000 |
| Co-58 | 0.0000 | 2.94E-09 | 1.94E-35 | 0.0000 | 9.68E-10 | 6.38E-36 | 0.0000 | 1.77E-17 | 1.17E-43 | 0.0000 |
| Co-60 | 55.1911 | 5.91E-08 | 3.26E-06 | 99.0125 | 7.28E-09 | 4.02E-07 | 98.2037 | 4.45E-17 | 2.46E-15 | 99.9993 |
| Highlighted | 100 | | | 100 | | | 100 | | | 100 |

[a]Based on 5 cm contamination depth.
DCF = Dose Conversion Factor

**Table 15. Potential Risk from Representative Quantities of Corrosion Products in Spent Reactor Fuels**

| Radionuclide | Activity % at 29 Years | Residential PRG | Relative Residential Risk at 29 Years | Residential Risk % at 29 Years | Agricultural PRG | Relative Agricultural Risk at 29 Years | Agricultural Risk % at 29 Years |
|---|---|---|---|---|---|---|---|
| Mn-54 | 0.0011 | 6.92E-01 | 1.56E-03 | 0.0001 | 3.69E-01 | 2.93E-03 | 0.0000 |
| Fe-55 | 44.8079 | 2.69E+03 | 1.67E-02 | 0.0011 | 8.21E-01 | 5.46E+01 | 0.0890 |
| Fe-59 | 0.0000 | 3.26E+00 | 2.30E-49 | 0.0000 | 1.20E+00 | 6.25E-49 | 0.0000 |
| Co-58 | 0.0000 | 2.66E+00 | 2.48E-27 | 0.0000 | 1.27E-01 | 5.19E-26 | 0.0000 |
| Co-60 | 55.1911 | 3.61E-02 | 1.53E+03 | 99.9988 | 9.01E-04 | 6.13E+04 | 99.9110 |
| Highlighted | 100 | | | 100 | | | 100 |

**Table 16. Representative Quantities of Transuranics in Spent Reactor Fuels**

| Radionuclide | $t_{1/2}$ (years) | Activity Ci/tonne[a] | Activity (%) | Relative Activity at 29 Years | Activity % at 29 Years |
|---|---|---|---|---|---|
| Np-237 | 2.14E+06 | 1 | 0.0005 | 5.18E-04 | 0.0016 |
| Pu-238 | 87.7 | 4,000 | 2.0734 | 1.77E+00 | 5.3954 |
| Pu-239 | 2.41E+04 | 500 | 0.2592 | 2.59E-01 | 0.7901 |
| Pu-240 | 6.56E+03 | 650 | 0.3369 | 3.36E-01 | 1.0255 |
| Pu-241 | 1.44E+01 | 150,000 | 77.7512 | 2.96E+01 | 90.1398 |
| Pu-242 | 3.75E+05 | 2 | 0.0010 | 1.04E-03 | 0.0032 |
| Am-241 | 4.33E+02 | 750 | 0.3888 | 3.76E-01 | 1.1482 |
| Am-243 | 7.37E+03 | 20 | 0.0104 | 1.03E-02 | 0.0316 |
| Cm-242 | 4.50E-01 | 35,000 | 18.1420 | 6.53E-13 | 0.0000 |
| Cm-244 | 1.81E+01 | 2,000 | 1.0367 | 4.80E-01 | 1.4647 |
| | Highlighted | | 99 | | 100 |

[a]Ci/tonne = curies per metric ton; $t_{1/2}$ = half-life

Likewise, to identify and quantify the major risk contributors from the identified transuranics, the calculated activity percentage at 29 years has been divided by the USEPA PRGs for both Residential and Agricultural land use scenarios. The resulting percentages of the relative risk are shown in Table 18. It can be seen from Table 18 that Pu-238, Pu-239, Pu-240, Pu-241, Am-241, and Cm-244 comprise greater than 99 percent of the risk from transuranics.

### 5.1.5 Combined Activity Dose and Risk

To identify and quantify the major dose and related potential risk contributors from all radionuclides produced by a reactor (excluding those associated with fuel) based on the quantities present in spent reactor fuels provided by Till and Meyer, the calculated activity percentage at 29 years has been multiplied by the USEPA inhalation,[33] ingestion,[34] and external[35] dose conversion factors for the combined sum of the fission products, activation products and transuranics. Both the radionuclides with the potential to contribute more than one percent of the total activity and the radionuclides with the potential to contribute more than one percent of the total dose and associated risk are reflected in Table 19. It can be seen from Table 19 that Sr-90, Cs-137, Co-60, Pu-238, Pu-239, Pu-240, Pu-241, Am-241, and Cm-244 comprise greater than 99 percent of the pathway dose potential and that Sr-90 and Cs-137 comprise greater than 99 percent of the risk potential from reactor produced contaminants excluding H-3, C-14. The other potentially significant radionuclides associated with reactors would include the fuel element radionuclides Th-228, Th-232, U-234, U-235, and U-238. Another radionuclide comprising at least 0.5 % of the radioactivity potentially present onsite but that contributes less than 1 percent of the dose and risk potential is Eu-155.

[33] Federal Guidance Report No.11.
[34] *Ibid.*
[35] Federal Guidance Report No.12.

**Table 17. Potential Dose from Representative Quantities of Transuranics in Spent Reactor Fuels**

| Radionuclide | Activity % at 29 Years | Inhalation DCF | Relative Inhalation Dose at 29 Years | Inhalation Dose % at 29 Years | Ingestion DCF | Relative Ingestion Dose at 29 Years | Ingestion Dose % at 29 Years | External DCF[a] | Relative External Dose at 29 Years | External Dose % at 29 Years |
|---|---|---|---|---|---|---|---|---|---|---|
| Np-237 | 0.0016 | 1.46E-04 | 2.31E-07 | 0.0189 | 1.20E-06 | 1.90E-09 | 0.0189 | 3.51E-18 | 5.55E-21 | 1.9429 |
| Pu-238 | 5.3954 | 1.06E-04 | 5.72E-04 | 46.7331 | 8.65E-07 | 4.67E-06 | 46.5119 | 7.60E-22 | 4.10E-21 | 1.4356 |
| Pu-239 | 0.7901 | 1.16E-04 | 9.16E-05 | 7.4889 | 9.56E-07 | 7.55E-07 | 7.5274 | 1.15E-21 | 9.09E-22 | 0.3181 |
| Pu-240 | 1.0255 | 1.16E-04 | 1.19E-04 | 9.7205 | 9.56E-07 | 9.80E-07 | 9.7706 | 7.44E-22 | 7.63E-22 | 0.2671 |
| Pu-241 | 90.1398 | 2.23E-06 | 2.01E-04 | 16.4253 | 1.85E-08 | 1.67E-06 | 16.6192 | 2.44E-23 | 2.20E-21 | 0.7700 |
| Pu-242 | 0.0032 | 1.11E-04 | 3.51E-07 | 0.0287 | 9.08E-07 | 2.87E-09 | 0.0286 | 6.43E-22 | 2.03E-24 | 0.0007 |
| Am-241 | 1.1482 | 1.20E-04 | 1.38E-04 | 11.2591 | 9.84E-07 | 1.13E-06 | 11.2602 | 2.18E-19 | 2.50E-19 | 87.6378 |
| Am-243 | 0.0316 | 1.19E-04 | 3.76E-06 | 0.3069 | 9.79E-07 | 3.09E-08 | 0.3079 | 6.59E-19 | 2.08E-20 | 7.2820 |
| Cm-242 | 0.0000 | 4.67E-06 | 9.30E-18 | 0.0000 | 3.10E-08 | 6.17E-20 | 0.0000 | 8.60E-22 | 1.71E-33 | 0.0000 |
| Cm-244 | 1.4647 | 6.70E-05 | 9.81E-05 | 8.0187 | 5.45E-07 | 7.98E-07 | 7.9553 | 6.74E-22 | 9.87E-22 | 0.3456 |
| Highlighted | 100 | | | 100 | | | 100 | | | 99 |

[a]Based on 5 cm contamination depth.
DCF = Dose Conversion Factor

**Table 18. Potential Risk from Representative Quantities of Transuranics in Spent Reactor Fuels**

| Nuclide | Activity % at 29 Years | Residential PRG | Relative Residential Risk at 29 Years | Residential Risk % at 29 Years | Agricultural PRG | Relative Agricultural Risk at 29 Years | Agricultural Risk % at 29 Years |
|---|---|---|---|---|---|---|---|
| Np-237 | 0.0016 | 1.30E-01 | 1.22E-02 | 0.3222 | 4.48E-04 | 3.53E+00 | 0.2892 |
| Pu-238 | 5.3954 | 2.97E+00 | 1.82E+00 | 48.1288 | 7.31E-03 | 7.38E+02 | 60.4765 |
| Pu-239 | 0.7901 | 2.59E+00 | 3.05E-01 | 8.0817 | 6.09E-03 | 1.30E+02 | 10.6299 |
| Pu-240 | 1.0255 | 2.60E+00 | 3.94E-01 | 10.4497 | 6.10E-03 | 1.68E+02 | 13.7749 |
| Pu-241 | 90.1398 | 4.06E+02 | 2.22E-01 | 5.8820 | 1.05E+00 | 8.58E+01 | 7.0340 |
| Pu-242 | 0.0032 | 2.73E+00 | 1.16E-03 | 0.0307 | 6.42E-03 | 4.93E-01 | 0.0404 |
| Am-241 | 1.1482 | 1.87E+00 | 6.14E-01 | 16.2676 | 1.32E-02 | 8.70E+01 | 7.1274 |
| Am-243 | 0.0316 | 1.66E-01 | 1.90E-01 | 5.0372 | 1.11E-02 | 2.84E+00 | 0.2330 |
| Cm-242 | 0.0000 | 3.22E+02 | 6.18E-15 | 0.0000 | 1.89E+01 | 1.05E-13 | 0.0000 |
| Cm-244 | 1.4647 | 6.69E+00 | 2.19E-01 | 5.8002 | 3.04E-01 | 4.82E+00 | 0.3948 |
| Highlighted | 100 | | | 100 | | | 99 |

**Table 19. Potential Dose and Risk from Representative Quantities of Produced Radionuclides in Spent Reactor Fuels**

| Radionuclide | Activity % at 29 Years | Inhalation Dose % at 29 Years | Ingestion Dose % at 29 Years | External Dose % at 29 Years[a] | Residential Risk % at 29 Years | Agricultural Risk % at 29 Years |
|---|---|---|---|---|---|---|
| H-3 | 0.1507 | 0.0000 | 0.0001 | 0.0000 | 0.0088 | 0.0019 |
| Kr-85 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Sr-90 | 21.7367 | 1.6565 | 1.6286 | 0.0148 | 12.4963 | 32.0820 |
| Zr-93 | 0.0012 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Tc-99 | 0.0088 | 0.0000 | 0.0001 | 0.0000 | 0.0047 | 0.0032 |
| Ru-106 | 0.0006 | 0.0000 | 0.0001 | 0.0005 | 0.0000 | 0.0000 |
| Sb-125 | 0.0487 | 0.0000 | 0.0009 | 0.0861 | 0.0140 | 0.0002 |
| I-129 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 |
| Cs-134 | 0.0687 | 0.0002 | 0.0316 | 0.4494 | 0.0582 | 0.0189 |
| Cs-135 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| Cs-137 | 39.0591 | 0.0732 | 12.2314 | 98.3511 | 86.8857 | 66.7764 |
| Pm-147 | 0.5779 | 0.0013 | 0.0038 | 0.0000 | 0.0001 | 0.0000 |
| Eu-155 | 1.2149 | 0.0030 | 0.0116 | 0.2228 | 0.0425 | 0.0007 |
| Mn-54 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Fe-55 | 0.0672 | 0.0000 | 0.0003 | 0.0000 | 0.0000 | 0.0002 |
| Fe-59 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Co-58 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Co-60 | 0.0828 | 0.0011 | 0.0140 | 0.8508 | 0.3044 | 0.1884 |
| Np-237 | 0.0006 | 0.0185 | 0.0163 | 0.0005 | 0.0006 | 0.0027 |
| Pu-238 | 1.9953 | 45.9221 | 40.0363 | 0.0004 | 0.0892 | 0.5600 |
| Pu-239 | 0.2922 | 7.3589 | 6.4794 | 0.0001 | 0.0150 | 0.0984 |
| Pu-240 | 0.3793 | 9.5519 | 8.4103 | 0.0001 | 0.0194 | 0.1276 |
| Pu-241 | 33.3355 | 16.1402 | 14.3054 | 0.0002 | 0.0109 | 0.0651 |
| Pu-242 | 0.0012 | 0.0282 | 0.0246 | 0.0000 | 0.0001 | 0.0004 |
| Am-241 | 0.4246 | 11.0637 | 9.6925 | 0.0214 | 0.0302 | 0.0660 |
| Am-243 | 0.0117 | 0.3016 | 0.2651 | 0.0018 | 0.0093 | 0.0022 |
| Cm-242 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Cm-244 | 0.5417 | 7.8795 | 6.8477 | 0.0001 | 0.0108 | 0.0037 |
| Highlighted | 99 | 100 | 100 | 100 | 99 | 99 |

[a]Based on 5 cm contamination depth.

### 5.2 RADIONUCLIDES ASSOCIATED WITH ACCELERATOR OPERATIONS

The radionuclides produced by accelerator operations depend on the composition of the targets that were irradiated and the types of particles that were accelerated. It appears that the Van de Graaff generators were primarily used to bombard tritium targets with deuterons to produce neutrons. The activation products produced are likely to have been similar to the activation products produced in reactors. This similarity would be due to the construction materials for both reactors and accelerators (e.g., hydrogenous concrete and steal) and the long-lived activation products would be comprised of some of the radionuclides listed in Table 10. Estimation of quantities is not possible at this time but would likely be small compared to activation products produced by the reactors.

### 5.3 RADIONUCLIDES ASSOCIATED WITH RESEARCH AND FABRICATION, USE, AND STORAGE OF RADIOACTIVE SOURCES

The primary radionuclides produced as a result of research include isotopes of uranium, plutonium, and neptunium (the same isotopes as those listed under the reactor operations discussed above), stored onsite in conjunction with the TRUMP-S program. Radionuclides Mn-54 and Co-60 were produced as a result of operations associated with the Corrosion Testing Laboratory. It is likely that the contamination onsite from these operations was relatively small compared to that from reactor operations given that the sources were either sealed or in storage rather than in active operations. The primary radionuclide associated with fabrication and use of radioactive sources was Pm-147, but may have also included Co-60 and Cs-137.

### 5.4 SUMMARY OF OPERATIONAL RELATED RADIONUCLIDES

Table 20 provides a summary of the SSFL Area IV historical operations-related radionuclides with half-lives greater than one year. The table also shows which radionuclides are expected to contribute more than 1 percent of the current activity, potential dose, and potential risk. The actual calculation of relative activity, dose, and risk could only be performed for radionuclides in spent reactor fuel. Radionuclides associated with fuel elements are assumed to have the potential to contribute more than 1 percent of the current activity, dose, and risk. For some radionuclides from reactors and other processes, no relative activity information is available and therefore the potential for contamination is unknown. In the absence of specific concentration or process knowledge information, they were not eliminated from the list of radionuclides that could have the potential to contribute greater than 1 percent of the total activity, dose, and risk.

## 6.0 CONCLUSION

From this evaluation, those radionuclides that have the potential to contribute significantly to human or environmental dose and risk after 29 years since operations were suspended in Area IV of SSFL have been identified. The list of major contributors may be used to prioritize analytical requirements for new samples to be collected for site characterization and risk assessment. The actual concentrations present in Area IV of SSFL and resulting risk to the public depend on the quantities of radionuclides that were released to the environment and the residual persistence in the environs after 29 years of decay and prior remediation efforts. That will be the focus of the radiological survey and sampling efforts currently in planning by USEPA and the dose/risk assessment aspect of the Environmental Impact Statement currently being developed.

**Table 20. Summary of the SSFL Area IV Historical Operations Related Radionuclides with Half-Lives Greater Than One Year**

| Radionuclide | $t_{1/2}$ (years) | Process Relationship | Potential to Contribute > 1% of Activity | Potential to Contribute > 1% of Pathway Dose | Potential to Contribute > 1% of Risk |
|---|---|---|---|---|---|
| Th-228 | 1.90E+00 | Reactor Fuel Element | Th-228 | Th-228 | Th-228 |
| Th-232 | 1.40E+10 | Reactor Fuel Element | Th-232 | Th-232 | Th-232 |
| U-234 | 2.46E+05 | Reactor Fuel Element | U-234 | U-234 | U-234 |
| U-235 | 7.04E+08 | Reactor Fuel Element | U-235 | U-235 | U-235 |
| U-238 | 4.50E+09 | Reactor Fuel Element | U-238 | U-238 | U-238 |
| Pu-238 | 8.77E+01 | Reactor Fuel Element | Pu-238 | Pu-238 | Pu-238 |
| Pu-239 | 2.40E+04 | Reactor Fuel Element | Pu-239 | Pu-239 | Pu-239 |
| Pu-240 | 6.60E+03 | Reactor Fuel Element | Pu-240 | Pu-240 | Pu-240 |
| Pu-241 | 1.44E+01 | Reactor Fuel Element | Pu-241 | Pu-241 | Pu-241 |
| H-3 | 1.23E+01 | Reactor Fission Product | H-3[a] | H-3[a] | H-3[a] |
| Se-79 | 6.50E+04 | Reactor Fission Product | | | |
| Kr-85 | 10.73 | Reactor Fission Product | | | |
| Sr-90 | 29.1 | Reactor Fission Product | Sr-90 | Sr-90 | Sr-90 |
| Zr-93 | 1.50E+06 | Reactor Fission Product | | | |
| Tc-99 | 2.13E+05 | Reactor Fission Product | | | |
| Ru-106 | 1.02E+00 | Reactor Fission Product | | | |
| Pd-107 | 6.50E+06 | Reactor Fission Product | | | |
| Cd-113 | 1.41E+01 | Reactor Fission Product | | | |
| Sb-125 | 2.76E+00 | Reactor Fission Product | | | |
| Sn-126 | 1.00E+05 | Reactor Fission Product | | | |
| I-129 | 1.57E+07 | Reactor Fission Product | | | |
| Cs-134 | 2.07E+00 | Reactor Fission Product | | | |
| Cs-135 | 2.30E+06 | Reactor Fission Product | | | |
| Cs-137 | 3.02E+01 | Reactor Fission Product | Cs-137 | Cs-137 | Cs-137 |
| Sm-146 | 1.03E+08 | Reactor Fission Product | | | |
| Pm-147 | 2.62E+00 | Reactor Fission Product | Pm-147 | | |
| Eu-152 | 1.35E+01 | Reactor Fission Product | | | |
| Eu-154 | 8.59E+00 | Reactor Fission Product | | | |
| Eu-155 | 4.71E+00 | Reactor Fission Product | Eu-155 | | |
| H-3 | 1.23E+01 | Reactor Activation Product | | | |
| Be-10 | 1.53E+06 | Reactor Activation Product | Be-10[a] | Be-10[a] | Be-10[a] |
| C-14 | 5.73E+03 | Reactor Activation Product | | | |
| Fe-55 | 2.73E+00 | Reactor Activation Product | | | |
| Ni-59 | 7.60E+03 | Reactor Activation Product | | | |
| Co-60 | 5.27E+00 | Reactor Activation Product | | Co-60 | |
| Ni-63 | 1.00E+02 | Reactor Activation Product | | | |
| Cd-113m | 1.41E+01 | Reactor Activation Product | Cd-113m[a] | Cd-113m[a] | Cd-113m[a] |
| Ba-133 | 1.05 E+01 | Reactor Activation Product | Ba-133 | Ba-133 | Ba-133 |
| Eu-152 | 1.35E+01 | Reactor Activation Product | Eu-152[a] | Eu-152[a] | Eu-152[a] |
| Eu-154 | 8.59E+00 | Reactor Activation Product | Eu-154[a] | Eu-154[a] | Eu-154[a] |
| U-233 | 1.59E+05 | Reactor Activation Product | U-233[a] | U-233[a] | U-233[a] |
| Np-237 | 2.14E+06 | Reactor Transuranic | | | |
| Pu-238 | 87.7 | Reactor Transuranic | Pu-238 | Pu-238 | |
| Pu-239 | 2.41E+04 | Reactor Transuranic | Pu-239 | Pu-239 | |
| Pu-240 | 6.56E+03 | Reactor Transuranic | Pu-240 | Pu-240 | |
| Pu-241 | 1.44E+01 | Reactor Transuranic | Pu-241 | Pu-241 | |
| Pu-242 | 3.75E+05 | Reactor Transuranic | | | |
| Am-241 | 4.33E+02 | Reactor Transuranic | Am-241 | Am-241 | |

**Table 20. Summary of the SSFL Area IV Historical Operations Related Radionuclides with Half-Lives Greater Than One Year (continued)**

| Radionuclide | $t_{1/2}$ (years) | Process Relationship | Potential to Contribute > 1% of Activity | Potential to Contribute > 1% of Dose | Potential to Contribute > 1% of Risk |
|---|---|---|---|---|---|
| Am-243 | 7.37E+03 | Reactor Transuranic | | | |
| Cm-242 | 4.50E-01 | Reactor Transuranic | | | |
| Cm-244 | 1.81E+01 | Reactor Transuranic | Cm-244 | Cm-244 | |
| H-3 | 1.23E+01 | Accelerator Activation Product | H-3 [a] | H-3 [a] | H-3 [a] |
| Be-10 | 1.53E+06 | Accelerator Activation Product | | | |
| C-14 | 5.60E+03 | Accelerator Activation Product | | | |
| Cl-36 | 3.01E+05 | Accelerator Activation Product | | | |
| Ar-39 | 2.69E+02 | Accelerator Activation Product | | | |
| Fe-55 | 2.73E+00 | Accelerator Activation Product | | | |
| Ni-59 | 7.60E+04 | Accelerator Activation Product | | | |
| Co-60 | 5.27E+00 | Accelerator Activation Product | | | |
| Ni-63 | 1.00E+02 | Accelerator Activation Product | | | |
| Mo-93 | 4.00E+03 | Accelerator Activation Product | | | |
| Nb-93m | 1.60E+01 | Accelerator Activation Product | | | |
| Nb-94 | 2.03E+04 | Accelerator Activation Product | | | |
| Tc-99 | 2.13E+05 | Accelerator Activation Product | | | |
| Ag-108m | 1.08E+02 | Accelerator Activation Product | | | |
| Cd-113m | 1.30E+01 | Accelerator Activation Product | | | |
| Sn-121m | 5.60E+01 | Accelerator Activation Product | | | |
| Pb-205 | 1.53E+07 | Accelerator Activation Product | | | |
| U-234 | 2.46E+05 | Research Radionuclide | U-234 [a] | U-234 [a] | U-234 [a] |
| U-235 | 7.04E+08 | Research Radionuclide | U-235 [a] | U-235 [a] | U-235 [a] |
| U-238 | 4.50E+09 | Research Radionuclide | U-238 [a] | U-238 [a] | U-238 [a] |
| Np-237 | 2.14E+06 | Research Radionuclide | Np-237 [a] | Np-237 [a] | Np-237 [a] |
| Pu-238 | 87.7 | Research Radionuclide | Pu-238 [a] | Pu-238 [a] | Pu-238 [a] |
| Pu-239 | 2.41E+04 | Research Radionuclide | Pu-239 [a] | Pu-239 [a] | Pu-239 [a] |
| Pu-240 | 6.56E+03 | Research Radionuclide | Pu-240 [a] | Pu-240 [a] | Pu-240 [a] |
| Pu-241 | 1.44E+01 | Research Radionuclide | Pu-241 [a] | Pu-241 [a] | Pu-241 [a] |
| Co-60 | 5.27E+00 | Research Radionuclide | Co-60 [a] | Co-60 [a] | Co-60 [a] |
| Cs-137 | 3.02E+01 | Research Radionuclide | Cs-137 [a] | Cs-137 [a] | Cs-137 [a] |
| Pm-147 | 2.62E+00 | Research Radionuclide | Pm-147 [a] | Pm-147 [a] | Pm-147 [a] |

[a] No relative activity information is available for these radionuclides from these processes and therefore the potential for contamination is unknown. In the absence of specific concentration information, they were not eliminated from the list to have the potential to contribute greater than 1 percent of the total activity, dose, and risk.
$t_{1/2}$ = half life

# 7.0 REFERENCES


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# APPENDIX A
# ABOUT THE AUTHOR

# ABOUT THE AUTHOR

Dr. Thomas L. Rucker received his Ph.D. from The University of Tennessee in Analytical Chemistry with an emphasis in Radiochemistry and a minor in Health Physics. He is currently Manager of Radiological Assessment and Protection for Science Applications International Corporation (SAIC), where he leads a team of health physicists and radiochemists in providing radiological characterization, assessment, and protection services. Dr. Rucker specializes in radionuclide measurement and dose assessment for health and environment protection and also provides expertise in other areas of analytical chemistry, environmental chemistry, and health physics, including environmental monitoring, waste management, radiological site characterization, and risk assessment. He has extensive experience in analytical chemistry, radiochemistry, radiological monitoring, dose and risk assessment, radiological site characterization, and environmental and waste management. His experience in analytical and radiochemistry includes laboratory management; laboratory automation; research and development; quality assurance/quality control (QA/QC) program management; document/procedure preparation and review; personnel training; method development; data interpretation; information management, and statistical analysis. He has expertise in the sampling, separation, and measurement of both radiological and nonradiological analytes. He has extensive experience in alpha and gamma spectroscopy, liquid scintillation counting, gas chromatography/mass spectrometry, and nuclear nondestructive and field analysis techniques. He also has extensive experience in analytical data evaluation, validation, and management.

His radiological monitoring, dose and risk assessment, and environmental and waste management experience includes evaluation and preparation of recommendations for radiological effluent and environmental monitoring programs; the interpretation and implementation of radiation protection regulations in technical basis documents for internal dosimetry, air monitoring, radiological survey, and contamination control; establishment of internal dosimetry bioassay programs; evaluation of nuclear accident dosimetry programs; development of site and facility characterization plans; development of analytical data summary reports; development and verification of characterization databases and dose calculation software; development of waste characterization plans; evaluation of waste characterization data; and preparation of waste minimization reports. He has participated in the development or review of environmental assessments (EAs), environmental impact statements (EISs), decontamination and decommissioning (D&D) plans and reports and D&D Funding Plans for NRC license termination, ALARA assessments, air and water quality studies, data management and validation studies, waste characterization plans; waste certification assessments, sampling and analysis plans (SAPs), data quality objectives, field sampling plans, quality assurance project plans (QAPPs), health and safety plans, remedial investigation reports, pathway analyses, dose assessments, and human health risk assessments.

Dr. Rucker's project experience in site characterization and risk assessment includes support to the Department of Energy (DOE) under subcontract to CDM Federal for the development of an Environmental Impact Statement (EIS) for the decommissioning of the Energy Technology Engineering Center at the Santa Susanna Field Laboratory. The project has involved the evaluation of historical processes and data and the development of a Data Gap Analysis Report identifying additional survey and sampling required to perform risk assessments required to evaluate the alternatives evaluated in the Environmental Impact Statement. Dr. Rucker serves as the lead radiological risk assessor and a radionuclide site characterization expert for the project.

He also provides support to the Department of Energy for radiological data collection, evaluation, dose assessment, and human health risk assessment under contract to Bechtel Jacobs Company, LLC, for the East Tennessee Technology Park Reindustrialization Program in Oak Ridge, Tennessee, and under contract to Restoration Services Incorporated for the Portsmouth Gaseous Diffusion Plant in Ohio. This support has included determination of extent and isotopic distribution of residual contamination, development of technical basis for radiological survey and sampling plans based on Multi-Agency Radiation Survey and Site Investigation guidance, development of survey and sampling plans and summary reports, and dose and risk assessment using RESRAD and RESRAD BUILD computer modeling codes as well as the use of EPA-approved modeling and slope factors.

As project manager he led a task to document the existing knowledge base for radiological characterization of the areas and facilities at DOE's Y-12 Weapons Complex and the East Tennessee Technology Park in Tennessee that are managed by Bechtel Jacobs LLC (BJC). He also supported for a Supplemental Site-Wide Environmental Impact Statement for the Los Alamos National Laboratory Site. He helped evaluate historical characterization data and exposure scenarios for a number of Material Disposal Areas (MDAs) containing legacy radiological waste from the site. This information was used to develop the chemical and radiological source term for air release to the public, transportation accidents, and worker accident exposures resulting from possible excavation of the waste from the MDAs for disposal at permanent repositories.

Dr. Rucker provided support for radiological site characterization studies for several Formerly Utilized Sites Remedial Action Program (FUSRAP) sites and DOE's Hanford site in Washington, and he served as project manager to review the existing characterization data found in UCN-2109 files associated with containers of Oak Ridge Reservation Legacy Low-Level Waste (LLLW) for WESKEM. The review provided quantitative evaluation of the uncertainties' impact on the the ability of each waste population to meet the waste acceptance criteria for the available disposal facility options.

Dr. Rucker has specialized training in Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) implementation, and the use of RESRAD, RESRAD-BUILD, and RESRAD-RECYCLE dose and risk modeling. Dr. Rucker's experience includes work with national laboratories, DOE defense facilities, DOE fuel cycle facilities, DOE waste storage facilities, EPA, NASA, Army Core of Engineers, commercial laboratories, and commercial instrumentation manufacturers.

Dr. Rucker is a member of the Health Physics Society and the American Chemical Society and is the author of numerous technical papers and publications, including several published in the Journal of Radioanalytical and Nuclear Chemistry. He has presented papers at national and international conferences, including the Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Third International Conference on Methods and Applications of Radioanalytical Chemistry, and the Southeastern Regional Meeting of the American Chemical Society.